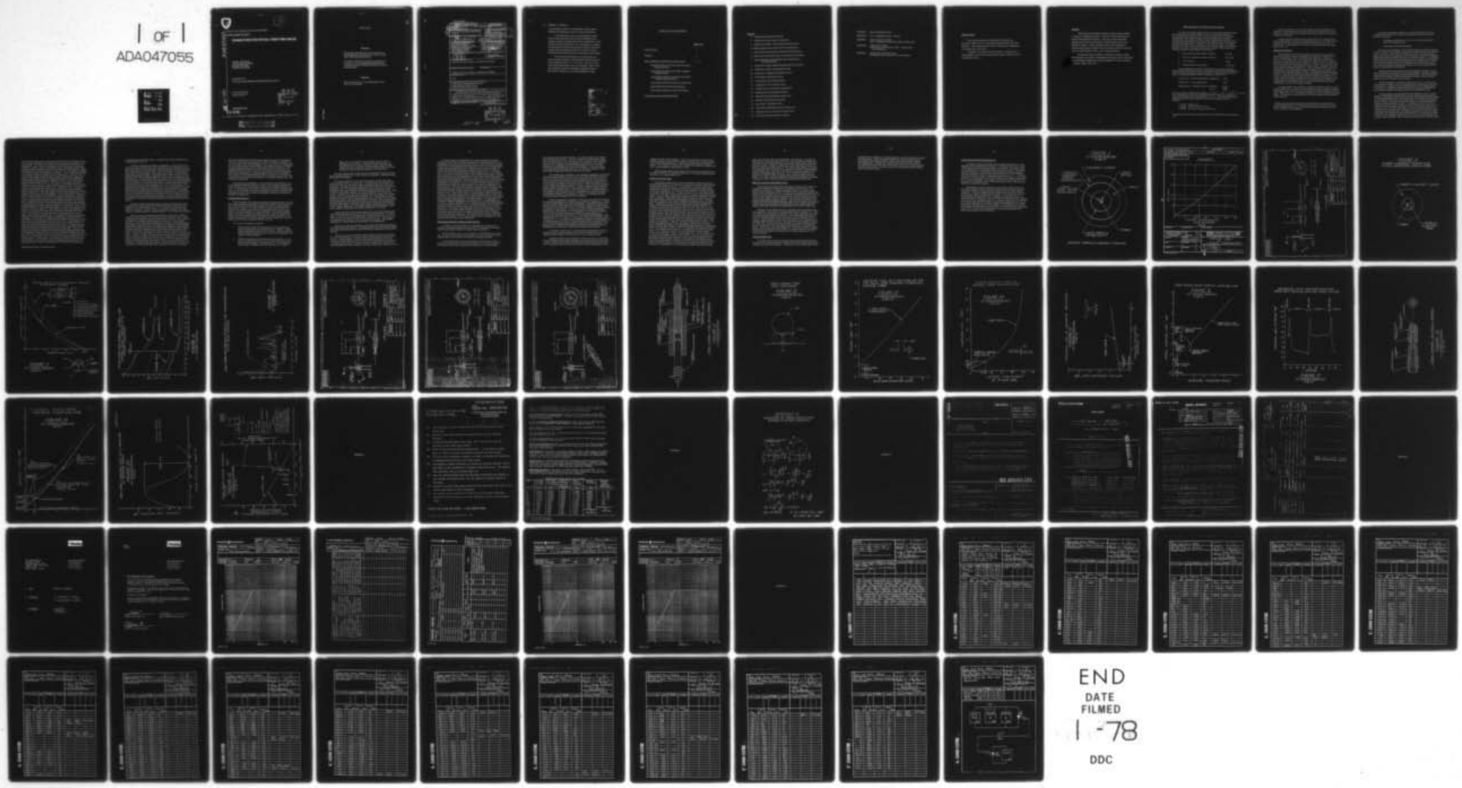
AD-A047 055 ITT CANNON ELECTRIC SANTA ANA CALIF F/G 9/1
CONNECTORS FOR OPTICAL FIBER TDM CABLES. (U)
NOV 77 R L MCCARTNEY DAAB07-76-C-1357
UNCLASSIFIED ECOM-76-1357-1 NL

1 OF 1
ADA047055



END
DATE
FILMED
1-78
DDC

12

B-5

AD A047055

Research and Development Technical Report

ECOM DAAB07-76-1357-1

CONNECTORS FOR OPTICAL FIBER TDM CABLES

Ronald L. McCartney
ITT CANNON ELECTRIC
666 East Dyer Road
Santa Ana, CA 92702

November 1977

First Semi Annual Report for Period 7 May 76 - 30 Jun 77

DISTRIBUTION STATEMENT
Approved for public release;
distribution unlimited.

PREPARED FOR

ECOM

US ARMY ELECTRONICS COMMAND FORT MONMOUTH, NEW JERSEY 07703

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: ECOM-76-1357-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Connectors for Optical Fiber TDM Cables.		5. TYPE OF REPORT & PERIOD COVERED: 1st semi-annual Report no. 1, 5/7/76 - 6/30/77
		6. PERFORMING ORG. REPORT NUMBER: 7 May 76 - 30 Jun 77
7. AUTHOR(s): Mr. Ronald L. McCartney		8. CONTRACT OR GRANT NUMBER(s): DAAB07-76-C-1357
9. PERFORMING ORGANIZATION NAME AND ADDRESS: ITT CANNON ELECTRIC, 666 East Dyer Road, Santa Ana, California 92702		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1S7 62705 AH94 W2/01
11. CONTROLLING OFFICE NAME AND ADDRESS: Commanders-USAECom, Attn.: DRSEL-TL-ME, Fort Monmouth, N. J.		12. REPORT DATE: November 1977
		13. NUMBER OF PAGES: 50
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 78p.		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered ... if different from Report)

Approved for public release; distribution unlimited

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fiber Optic Hermaphroditic Connector
Three-Sphere Alignment Ferrule
Strength Member Cable Clamp

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The fiber optic communication system to which this contact is directed requires that each optical connection suffers an optical loss no greater than 1.0 - 1.5 dB. This low loss is required if the communication system is to function properly over distances of up to 8 km without excessive error rates. In addition, the connector hardware must be hermaphroditic.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

389 990

20. ABSTRACT (Continued)

environmentally sealed, and isolate cable strains without affecting the performance of the six optical connections.

It was discovered early in the development program that the fiber optic ferrule was the major challenge in the connector design and greatly affected the configuration of most internal connector components. As a consequence, a program was initiated to design a hermaphroditic connector shell and a strength member termination which was versatile enough to accommodate foreseeable ferrule and alignment sleeve designs.

The first major development and testing effort was directed toward achieving a fiber alignment concept capable of simple application and 1.0 - 1.5 dB loss. The major portion of this Semi-Annual Report will be a descriptive history of the fiber alignment concepts investigated, alignment analysis, test results, conclusions, and recommendations to date.

TABLE OF CONTENTS

FIGURES:

APPENDIX A	Sphere Specification Sheet
APPENDIX B	Fiber Installation Fixture Analysis
APPENDIX C	Sand and Dust Test Report Wyle Laboratories per MIL-STD-202E, Method 110A
APPENDIX D	Vibration Test Report Parker Hannifin per MIL-STD-202E, Method 204C, Test Condition A
APPENDIX E	Temperature Cycling Test Report Per MIL-STD-202, Method 107, Test Condition A

INTRODUCTION:

This report describes the development of a single fiber alignment system for use in a six-channel hermaphroditic fiber optic connector. The connector will be used to interconnect a strengthened six-channel fiber optic cable.

Included in this report are the test results, conclusions and recommendations of all ferrule and alignment designs which have been investigated to date.

PURPOSE:

Fiber optic communication systems are unique when compared to coaxial or twisted pair systems. They are neither affected by nor radiate electromagnetic radiation. They have a higher bandwidth capacity and are lighter and smaller in diameter than conventional electrical systems. These capabilities are a great advantage in military communication systems since the cable is intrusion-resistant, can carry large amounts of data, and is easily deployed.

The purpose of this contract is to develop a connector which will terminate a six-channel strengthened fiber optic cable as described in the Technical Guidelines of Contract DAAB07-76-C-1357 issued by USAECOM, dated 1 May 1976.

FIBER ALIGNMENT CONCEPTS AND TEST RESULTS

The heart of any fiber optic connector is the optical alignment system. The requirements of contract DAAB07-76-C-1357, which was awarded to ITT Cannon Electric on April 14, 1976 for the development of a six-channel hermaphroditic fiber optic separable connector requires that an optical coupling loss not exceeding 1.0 dB for mated hermaphroditic plugs and 1.5 dB for mated plug-receptacles be achieved. The coupling loss is to be obtained using Corning Glass Works Corguide^{tm}-6 Corning #1010 cable. The cable consists of 7 optical fibers, six of which are to be terminated in a fiber optic connector and used in an optical transmission network. Each fiber has the following dimensions and strength specifications*:

1.	Outer Coated Diameter (Buffer Diameter)	132 ± μm
2.	Outer Fiber Diameter (Classing Diameter)	125 ± 6 μm
3.	Core Diameter	85 μm
4.	Strength Screen Test (Tensile)	20,000 psi

A direct approach to coupling optical fibers is to use the available jeweled ferrule/guide sleeve concept. An analysis of the lateral alignment and optical coupling loss which would theoretically be expected using Corguide-6 fiber in a jeweled alignment system is as follows((Refer to Fig. 1)

Mated Fiber - Jewel orfice diameter concentricity	15 μm
Mated Fiber - Ferrule concentricity	10 μm
Mated Ferrule - Alignment sleeve concentricity	10 μm
TOTAL	35 μm

The most probable concentricity deviation is $L = [(15)^2 + (10)^2 + (10)^2]^{1/2} = 20.6\ \mu m$ This corresponds to a fiber core displacement of 24% which is a lateral alignment induced optical loss of 1.6 dB (Refer to Fig. 2). The total expected most probable optical loss for a jeweled pin and socket alignment system is therefore:

-0.30 dB	Fresnel Loss
-1.60 dB	Lateral Misalignment Loss
-1.90 dB	Total Most Probable Optical Loss

*Corning Glass works Optical Waveguide Products Standard Fiber Specifications, 6/75

Since a coupling loss of 1.90 dB is greater than the specification requirement, the development of a ferrule design which compensates for variations in the fiber outer coated diameter and precludes alignment mechanism clearances is required.*

A ferrule design which potentially compensated for the inherent fiber outer coated diameter variations and eliminated the need for alignment sleeve clearance would reduce the expected optical coupling loss to 1.0 dB. To achieve this 1.0 dB requirement, the three-rod nylon ferrule was developed (Refer to Fig. 3).

THREE-ROD APPROACH

A three-rod ferrule with rubber hourglass alignment sleeve was first described in ITTCE's proposal for USAECOM Solicitation No. DAAB07-76-Q-1307, dated November, 1975. This ferrule was made from a deformable, pliable, nylon material which was molded into a ferrule having three equal and parallel alignment rods at its mating end. These rods serve to align the fiber that had been epoxied into the body of the ferrule. This assembly would then be pressed into a rubber alignment sleeve in order to compress the legs around and align the fiber (See Fig. 4). The concept behind this design was the following: The Corning fiber varied in diameter from 125 to 139 μm. To compensate for the fiber diameter variation, a deformable alignment system is required. One method of achieving a deformable alignment system is through the use of a rubber alignment grommet which stretches as the ferrule is inserted, thereby applying a compressive force to the three aligning rods. This compressive force uniformly distorts the rods around the fiber, thereby locating the fiber at the geometric center of rods and alignment grommet while compensating for the fiber diameter variations.

An approximation to the amount of diametrical movement which the nylon ferrules would have to expand the rubber grommet in order to generate sufficient compressive force to press the nylon rods around the fiber diameter was developed (Refer to Fig. 5). The alignment grommet was made of ethylene-propylene rubber. The ferrule was made from nylon which was pliable and would indent around the fiber.

*(Please note the foregoing analysis was accomplished at the beginning of the development effort. It is believed today that the components of a jewel/ferrule alignment system can be designed/fabricated with dimensional accuracies to meet the 1dB requirement).

The primary requirements imposed on a three-rod ferrule for use as a compensator and locator in the optical interconnection mechanism outlined on previous page are:

1. Rod diameter uniformity both in the rod's physical dimensions and in the material density.

2. A high degree of material pliability.

The dimensional uniformity of the individual alignment rods was critical. In order to align the mating fibers, the geometric centers of each of the ferrules had to be coaxial. This could be achieved only if each of the three ferrule aligning rods had the same diameter, thereby forming an equilateral triangular configuration which positioned the fiber at its geometric center. If an opposing three-rod ferrule did not have equal diameter rods, a geometric center displacement would occur causing lateral misalignment of the mating fibers. As long as the three-rod ferrules are in the configuration of an equilateral triangle, their opposing geometric centers will be coaxial even if the common rod diameters of mating ferrules are different.

Material density variations must also be uniformly controlled. As the rods are compressed onto the fiber during interconnection, the least compression resistant rod will displace more than the other two. This will effectively reduce the rod diameter, thereby displacing the geometric center as would happen if the rods' diameters were not equal.

Material pliability is essential in a three-rod system. The rods must indent around the fiber in order to compensate for the variations in fiber outer coat diameter. In addition, the three aligning rods must be flexible enough to conform to the aligning grommet channel without lateral displacement of their geometric centers even when ferrule body displacements occur.

Optical coupling loss measurements were obtained as follows: A six-channel, strengthened, ITT fiber optic cable 100 meters long was coupled to an International Audio Visual "Fire" 5-E Grade A light emitting diode by placing the six connector fibers and one additional fiber in a hex pack configuration inside a ferrule. The ferrule was rigidly mounted on an adjustable stand and optimally positioned against the LED. The emitting end of the cable was stripped and the fibers were individually bonded into separate receiving ports which held a DV 444 A EGG photodiode. The fibers were individuallr mode stripped at both the receiving and emitting end of the cable with corona dope to eliminate any cladding light. The LED was activated and reference output light levels were recorded for each individual fiber. The system was allowed to remain in this activated state for two days in order to insure LED and mechanical support stability. After insuring that the system was optically stable,

the cable was severed at the center and three-rod nylon ferrules were attached to the severed fiber ends and inspected for surface quality, cleanliness, and axial position. The fibers were installed in a connector housing which was designed to contain, house, and properly support the alignment mechanisms and cable support hardware of the three-rod optical alignment system. During installation of the six optical fibers, two fibers broke. The optical evaluation was completed using the remaining four channels. Upon coupling the connector it was found the individual channel losses ranged from 3.5 dB to 12.0 dB. It was also found during evaluation that the optical coupling loss could be decreased if the connector was only partially uncoupled and then retightened. The resulting optical coupling loss ranged from 6 dB to 0.36 dB after fifteen partial couplings (Refer to Fig. 6). The reason for the initial high optical coupling loss was that the 'O'-ring spring was not sufficiently strong to overcome the frictional restraining force of the alignment grommet. This created a significant gap between the mated ferrules. Subsequent partial connector matings pushed the ferrules closer together with a corresponding reduction in optical coupling loss. After nine mating cycles the back restraining nut on the connector became loose and was tightened. This had the effect of pushing the ferrules closer together with a reduction in optical coupling loss as shown in Fig. 6. Because of the test results it was decided to redesign the alignment system by positioning the ferrules further forward which would allow the contacts to penetrate further into the alignment grommet and abut with a preload of approximately one pound. With this change it was found that the nylon legs receded axially due to creep exposing the fibers to compressive stress. This allowed the fibers to come into direct contact, to buckle, and, consequently, fracture at the ferrule bond line. This appeared to happen spontaneously even after the system had been coupled and was functioning properly for several hours. The solution to the creep problem was felt achievable by using a stiffer material for the alignment rods. To overcome the problem of alignment relaxation, a Valox* three-rod ferrule was developed. It was felt that the glass filled Valox would have enough deflection capability that the rods would indent and take up the diameter deviations in the fiber. Measurements of the nylon and Valox showed that the Young's modulus for nylon was 83,000 psi whereas the glass filled Valox modulus was 415,000 psi. A ferrule was built using the same molds that had been used for the nylon except that gas bleed holes were placed in the mold at the ends of the ferrule rods. This was required because gasses generated in the Valox material inhibited proper filling. The ferrules were molded and it was found that the fibers inserted easily into the system and the ferrules could be easily pressed into the alignment grommet. However, the Valox was found to be too stiff to be properly deflected by the rubber grommet. In other words, any movement at the back end of the ferrule would generate a rocking action within the alignment grommet thereby misaligning the fibers. This was catastrophic to the system because the inter-

*Registered Trademark of General Electric

connections were extremely erratic, especially upon final tightening of the connector (Refer to Fig. 7).

In order to overcome this problem of instability, it was felt that by reducing the cross-sectional area of the alignment rods the flexibility could be made equal to that of the nylon system while maintaining the high creep resistance obtainable in the Valox system. Using this concept, a metal three-rod ferrule (Fig. 8) was developed. The concept used copper tubes which were experimentally found to indent a sufficient amount to make up for most of the deviation in the fiber's diameter under loads which could be generated by the rubber grommet. It was felt that with this material, and if the cross-sectional area was reduced thereby reducing the moment of inertia, the desired flexibility could be achieved. A system was built where the three tubes were molded to the ferrule body and the cross-sectional area of the tube was reduced. The metal tubes were found to be as flexible as the nylon, but because of the three different bending moments of the rod assembly, the configuration was quite stiff and the rubber grommet would not flex the aligning rods. Any movement at the back end during coupling or tightening would cause severe movement of the front end where the alignment was occurring. Also, the reduced length of the aligning rods reduced the generating force of the rubber grommet causing the ferrule to be even more unstable when flexure occurred at the back of the system.

The fourth concept developed utilized a three-rod ferrule with a metal restrictive band pressed over the three metal rods after the fiber had been mounted into the ferrule (Refer to Fig. 9). The metal band achieved the required consolidation, however, the system was quite unstable in the rubber alignment grommet sleeve due to ferrule stiffness. This system was abandoned.

The fifth system incorporated a Valox ferrule pressed into a metallic circular tube and aligned in a split alignment split alignment sleeve, thereby compressing the Valox rods around the fiber (Refer to Fig. 10). The outside of this sleeve was machined and concentric to the ferrule. The machining achieved a system which pressed deformable rods around a fiber and provided concentricity to an outer sleeve. The ferrule was aligned in a split alignment sleeve which stabilized the ferrules overcoming the deflection and instability problems which were paramount in the other rubber grommet so that it would float and also achieve environmental sealing when the connector was fully mated. A rubber 'O'-ring spring was used to drive the ferrules into the aligning sleeve. With this design, the creep problem of the ferrule was eliminated because the ferrule was metal, except for the Valox alignment rods which did not protrude beyond the metal ferrule. The design achieved the highest stability of any of the ferrule designs investigated. However, two problems were encountered: the spring loaded split alignment sleeve required a high axial force to overcome the friction drag necessary to achieve total ferrule penetration.

The force requirements were above eight pounds and could not be generated with an 'O'-ring spring with its limited 0.050 inch deflection capability. A coil spring with a rate of approximately 200 lbs. per inch and a wire diameter of 0.035 inches would have been needed. This spring would have increased the ferrule diameter from 0.140 to 0.190 inches which was excessive. The second problem encountered was that the density of the Valox rods varied sufficiently from rod to rod to give a 12.5 μm geometric center displacement. This density variability was a molding problem which was not correctable. The resulting 12.5 μm displacement resulted in a maximum 25 μm lateral misalignment which amounted to an additional 2.0 dB optical coupling loss. The concept was abandoned.

After extensive investigation, it was concluded that attainment of sufficient material uniformity in plastics, either in their modulus parameters or in their diameter, was not sufficient to achieve the alignment necessary for a 1.0 - 1.5 dB interconnection and/or stable enough to prevent creepage which results in fiber breakage. The three-rod approach (concepts 1 through 5) was abandoned in favor of an all metallic three-sphere ferrule with self-seating alignment characteristics.

THREE-SPHERE APPROACH

The three-sphere keyed ferrule self-aligning concept consists of a metal ferrule body containing three grade 25,4400 cress spheres which are sized so as to create a hole whose effective diameter will pass the largest Corning fiber diameter (139 μm). The system is keyed, which properly orients the spheres so that during mating they will automatically nest within the intersticies of the three spheres of the opposing ferrule. The standard aligning spheres are readily available at nominal cost with tolerances typically one micron or better in diameter (Refer to Specification Sheet, Appendix A). The spheres are attached to the ferrule body with a metal retaining cap, which is pressed onto the body of the ferrule (Refer to Fig. 11).

The system is assembled as follows:

1. Three precision spheres are loaded into a sphere retention cap which is hand pressed onto the ferrule body. Seating is attained under an approximate axial load of 15 pounds. After assembly the spheres protrude nominally 125 μm, which allows interference free seating of opposing ferrules.

2. The fiber is installed from the end opposite the spheres. Its location is obtained through the use of a fourth sphere which rests within the three spheres. The Diameter "D_2" of the positioning fourth sphere is determined from the equation $D_2 = 2.725D_1$.

Where "D_1" is the diameter of the aligning spheres, refer to Appendix B for derivation. Holding the ferrule vertically with the sphere end up, the fiber is properly located when the fourth sphere just begins to lift from its seated position (Refer to Fig.12). The fiber is then clamped and epoxied to the ferrule body.

The three-sphere keyed ferrule single fiber alignment concept was evaluated for optical coupling loss, sand and dust susceptibility, vibration damage, and thermal shock effects.

The optical coupling loss test was an evaluation of fiber and ferrule-induced optical losses. As a first step, a 10 meter length of Corguide-6 fiber was removed from the Corning 1010 cable and inserted between an LED and a photodiode. The fiber was mode stripped with corona dope both at the LED and photodiode ends. The fiber/LED/photodiode system was allowed to reach thermal and mechanical stability which required approximately four hours. Once an optical output power reference had been established, the test fiber was cleaved. More than one cleaving was required since the cleaved ends showed fracture marks which propagated into the fiber core. Unfortunately, this end preparation sequence used up approximately ten inches of fiber so that the final mating ends were not from adjacent positions in the fiber. The non-terminated free state fiber ends were mounted to a five degree of freedom micrometer adjustment optical stage. Using this optical stage, coupling loss as a function of gap, lateral displacement, and angular misalignment were obtained. This data is plotted as free space data curves in Figures 13, 14, and 15.

Figure 13 illustrates the optical coupling loss of the non-terminated free state Corning fiber as a function of its gap to core diameter ratio. It is interesting to note that the lowest coupling loss achieved (at zero gap) is 1.14 dB when 0.30 dB loss should be achieved due to Fresnel losses. The reasons for this additional 0.84 dB loss is due to end surface angularity, core diameter mismatching, numerical aperture mismatching, and contamination.

Figure 14 is a plot of coupling loss data obtained for lateral displacement in percent of fiber core diameter. The data correctly shows the optical coupling loss increasing without limit as lateral displacement approaches the fiber core diameter.

Figure 15 is a plot of measured off axis angular coupling loss deviations. The loss is linear within the 3 degree range of measurement and amounts to a loss of 0.3 dB per degree. The fibers which were evaluated for free space coupling loss were terminated in two three-sphere keyed ferrules and evaluated for optical coupling loss as a function of gap to core diameter, which is the only independent adjustable variable in the three-sphere keyed alignment system.

By using Figure 13 to extrapolate the ferrule terminated fiber optical coupling loss data from the initial uncoupled ferrule engagement (Point 1) to a hypothetical free space zero gap position (Point 2) and the coupling loss data from the fully coupled ferrule engagement position (Point 3) to the hypothetical coupled zero gap position (Point 4), estimates can be made of the fiber and ferrule-induced optical losses of the coupled ferrule assembly. Figure 16 shows that of the 3.15 dB extrapolated optical coupling loss, 0.3 is Fresnel loss, 1.2 is fiber-induced loss, and 1.65 dB is ferrule-induced loss. The difference between the 1.2 dB hypothetical zero gap ferruled free space value and the 0.84 zero gap measured unferruled free space value is due to additional fiber mating surface angularity caused by rotational movement of the fiber during installation into the ferrules. The 1.65 dB ferrule-induced coupling loss is a combination of two effects, excess hole size and off axis deviations of the fiber within the ferrule body which translate into lateral misalignment at the mating position. The keyed ferrule aligns the mating fibers with 899 μm diameter spheres arranged in groups of three; the effective hole size between spheres is 137 μm and accepts a fiber whose measured outside diameter is as small as 124 μm. This could amount to a 12 μm maximum lateral displacement. In addition, the orifice through which the fiber protrudes acts as a pivot point through which off axis deviations of the fiber within the ferrule body are translated into lateral misalignments at the mating position. By using Figure 14, the effective lateral misalignment, which results in a 1.65 dB coupling loss, is 24.3 μm, which is equivalent to a 3.2 degree deviation from axial alignment. As can be seen from Figures 13 and 14, the optical coupling loss is much more sensitive to lateral deviations than to gap by a factor of 12 to 1 in the near field range. The residual, gage measured, excess fiber gap (Refer to Fig.16) is 69 μm and is a result of fiber movement during epoxy curing operations. The Corning fiber was found to be extremely brittle and subject to breakage during normal handling operations. This made application testing very time-consuming and difficult. The testing sequence had to be repeated four times before an unbroken channel was established.

PRELIMINARY TESTING OF THREE-SPHERE FERRULES

In addition to optical coupling loss measurements, sand and dust, vibration, and thermal cycling tests have also been conducted on the three-sphere keyed ferrules mounted in a single channel connector.

The sand and dust test was run according to MIL-STD 202E test method 110A, the test procedure reported in Appendix C, on five three-sphere keyed ferruled fibers, two of which were mounted on connector hardware.

It was found that the sand and dust pitted the fiber glass end face. It should be noted that there was no fiber shattering, but only minor chipping even though the fiber was unsupported and cantilevers out approximately

0.014 inches from the sphere's support. The mating surfaces were cleaned after sand and dust exposure. The test resulted in 6 dB additional optical loss per mated ferrule. It is interesting to note that fiber on the receptacle side of the test connector was not damaged by the sand and dust exposure. Ferrules in the receptacle are recessed approximately 10 mm. This gap excluded the sand particles from the ferrule interface. A possible solution to the sand and dust pitting problem may be to provide a protective shroud which axially slides back when the connectors are mated.

The vibration test, Appendix D, was conducted separately in three axial directions at accelerations of 10 g's over a nine-hour period with excursions from 10 to 500 Hz. The results of the test showed that the spheres did not loosen in their retention cap and no fiber breakage occurred. The conclusion is that the ferrule system is quite stable and not subject to degradation due to the vibration environment at the tested levels. These tests were conducted in both a mated and unmated condition. Optical evaluations were taken both before and after vibration tests. An increase of 1.56 dB in optical coupling was recorded. This was found to be due to instability in the optical reference. (Additional optical equipment has been installed in the system to eliminate the instability problem.) The conclusion is there is no significant optical coupling efficiency degradation due to the vibration.

Thermal cycling tests, Appendix E, were run on the system to determine the effects of temperature on the fiber and the connector coupling loss. Quartz is more thermally stable by an order of magnitude. Temperature induced movements may result in fiber protrusion from the ferrule causing the fiber to carry the full load of the connection. Also, if the fibers receded, the interconnection would have a higher dB loss. The thermal test was conducted according to MIL-STD-202, Test Method 107, Test Condition A, at a temperature range of -55° to $+85^{\circ}$C and was continually monitored for optical changes as is described and illustrated in Appendix E. The system showed repeatable cyclic optical deviation of +1.0 dB to -6.5 dB from the initial room temperature level (Refer to Fig. 17). An absolute room temperature coupling loss measurement was not obtainable due to the lack of a reference measurement on uncleaved fiber. As yet, the mechanism by which change is occurring is not understood, but is believed due to a complicated interaction between the connector and ferrule. Additional tests will be run to understand and eliminate this problem.

As a result of these tests, it was felt that an improvement in the fiber alignment system could be obtained if the fiber was clamped by the three aligning spheres instead of being guided as in the key ferrule design.

A sketch of the ferrule construction is shown in Figure 18. The three-sphere adjustable ferrule's main advantage over the rigid orifice ferrule design is that it creates an adjustable fiber orifice which clamps the fiber and aligns it to the geometric center of the nesting spheres while compensating for minor

variations in fiber outside diameter. This is accomplished by using 794 μm diameter spheres instead of 889 μm diameter spheres used in the three-sphere keyed ferrule design installed on a spring loaded ramp within the retention sleeve. Use of grade 25, Cress 4400, standard ball bearings for spheres provides lateral alignment concentricities of 1 μm.

Fifty prototype ferrules were made and evaluated in three separate tests. The three tests were: (1) optical coupling loss; (2) ferrule coupling engagement force; (3) contamination tests.

OPTICAL COUPLING LOSS

The optical coupling loss test was an evaluation of fiber and ferrule induced optical losses as a function of the independent variable "fiber gap/core diameter ratio" (Refer to Fig. 19). As a first step, a 10 meter length of Corguide-6 fiber was removed from the Corning 1010 cable and inserted between an LED and a photodiode. The fiber was mode stripped with corona dope both at the LED and photodiode end. A fiber was placed in the same fiber holding mechanism as the fiber to be tested and used as a monitor of LED optical power output. Once an optical output power reference had been established, the test fiber was cleaved. More than one cleaving was required since the cleaved ends showed fracture marks which propagated into the fiber core. The fiber ends were mounted in a five degree of freedom micrometer adjustment optical stage. Maximizing the power output/minimizing the optical coupling loss resulted in the data plotted as the free space data curve #1 of Fig. 19. The resultant measured zero gap optical loss was 0.45 dB. This curve was used as the basis for evaluating the optical coupling loss associated with the fibers mounted in three-sphere adjustable ferrules. The second test sequence was to duplicate the free space test using the same fibers mounted in three-sphere adjustable ferrules. The fiber alignment tests conducted on ferrules were accomplished by both minimizing (fiber position optimized) the optical coupling loss at each gap increment (Curve 2) and in the unmaximized state (Curve 3 - fiber position non-optimized). Figure 19 illustrates several items of interest. At a gap to core diameter ratio of 0.828, the aligning spheres began to couple, thereby laterally repositioning the mating fibers independent of the manipulative stages. In both cases, (Curves 2 and 3) the ferrules self-aligned and resulted in a 1.30 dB coupling loss at zero gap. By extrapolating the maximized data, Curve 2, to the zero gap position, the fiber and ferrule induced coupling losses can be extracted. Of the 1.30 dB coupling loss, 0.3 dB is Fresnel loss, 0.6 dB can be attributed to ferrule induced losses. We have determined that the ferrule induced coupling losses were due to off axis misalignment of the fiber within the ferrule body and were 1.25 dB lower than the ferrule induced losses in the keyed design. Internal body to fiber clearance allowed the fiber to pass through the spheres at an angle causing a lateral misalignment of the fiber ends. The difficulty can be corrected by providing two rows of spheres

which align off each other and independently clamp the fiber. The fiber induced loss of 0.60 dB was found to be due to non-perpendicular mating fiber end faces and core diameter and index mismatched effects which analytically prove to be minor. In order to confirm this, a free space fiber test was run where one fiber was axially rotated +/- 180 degrees with respect to the other. The results are shown in Figure 20 and indicate a sinusoidal 1.09 dB variation in the coupling loss. This value is the total coupling loss deviation due to rotation of non-parallel fiber end faces. The 0.6 dB fiber induced loss of Figure 19 is simply the value at the particular installed position within the ferrule. As a result, ITT Cannon Electric is presently evaluating the cleaving procedures in order to produce axially perpendicular mating fiber ends.

FERRULE COUPLING ENGAGEMENT FORCE

Three-sphere adjustable ferrule mechanical coupling tests were run to evaluate the keying and coupling force requirements of the ferrule. Two ferrules were mounted in a simulated installed position on an Instron (calibrated tensile/compression tester). The ferrules were opposingly aligned and capable of being rotated so as to have rotational misalignment (Refer to Fig. 21). The two curves shown in Figure 21 illustrate the mean and standard deviation of the vertical mating force (Fv) required to cause rotational alignment of two opposing three-sphere adjustable ferrules. The stall line represents the coefficient of friction (K) between opposing spheres at each angular misalignment position based upon the theory that coefficient of static friction equals the tangent of the angle between the vertical mating force and the normal force.

Alignment motion/sliding will only take place when the frictional force component (F_R), is less than the opposite applied force component (F). Therefore, mating will take place if the tangent of the initial engagement angle (Θ) is greater than the coefficient of friction. If the engagement angle (Θ) is too small, the restraining force (F_R) will be greater than the alignment force (F) causing a locking condition which cannot be overcome with the application of a greater vertical mating force (F_V). The angle (Θ) at which locking occurs is: $(\Theta) = \text{Tan}^{-1}(K)$. As can be seen from the data, the vertical mating force (F_V) does grow drastically beyond the stall line intercept and is consistent with theory. The results of this data indicate that a viable way to insure coupling alignment with an adequate safety margin is to key the ferrules to less than a total rotational deviation of 25 degrees with a vertical mating force of 1.5 pounds or greater.

CONTAMINATION TEST

One of the main concerns of the three-sphere adjustable ferrule design has been the fear that dust particles trapped between the aligning spheres and the fiber may cause fiber breakage. A test was run where 1 μm alumina polish-

ing compound was placed on the aligning spheres in the form of both dry powder and a wet slurry. A fiber was placed between the aligning spheres and the contaminated spheres were caused to spring impact the fiber approximately two hundred times. The fiber was axially moved during the test in order to put compressive and tensile stress on the fiber to insure that alumina particles were in the impact area. The test resulted in no broken fibers and no visible scratch marks on the fiber.

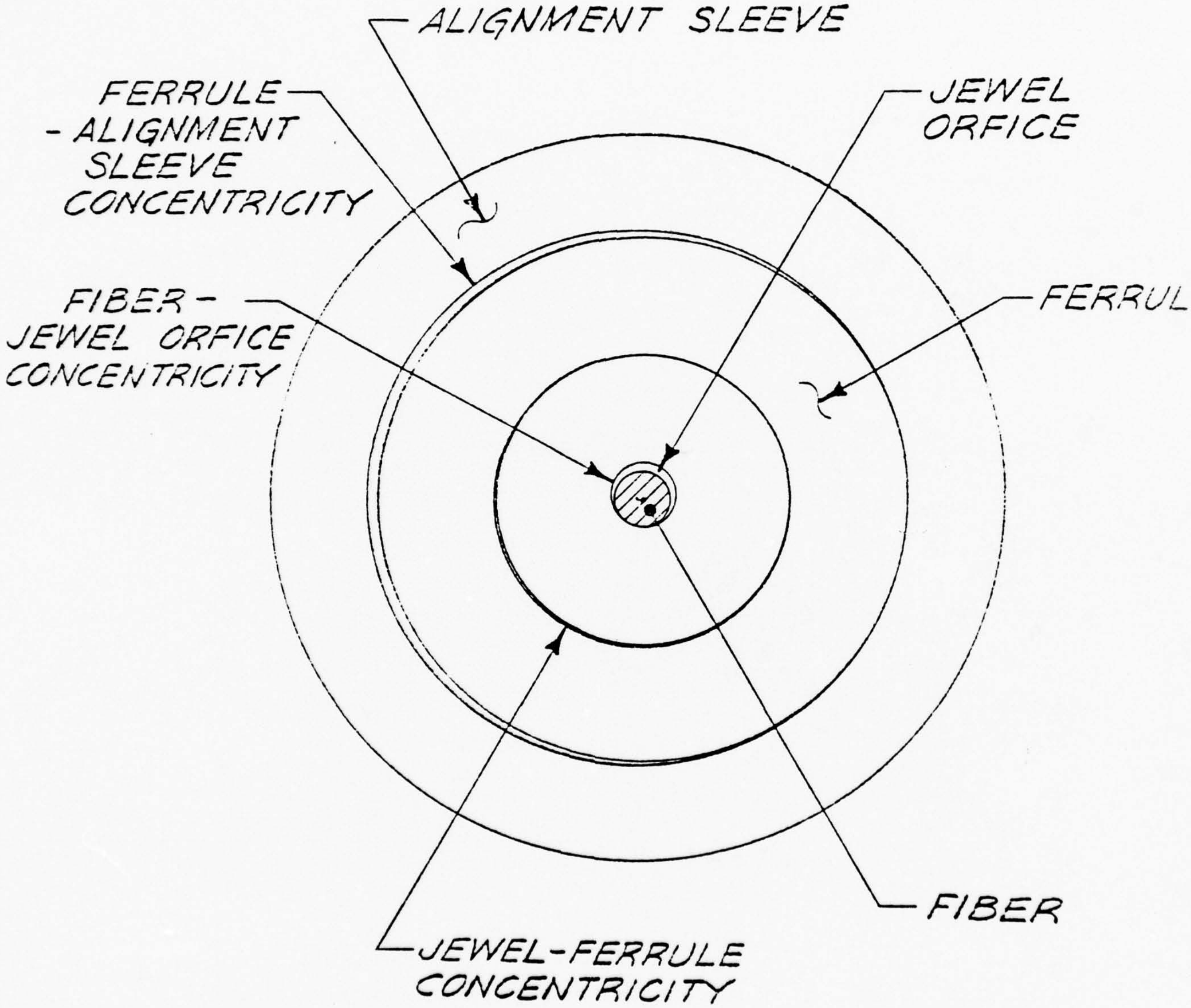
CONCLUSIONS AND RECOMMENDATIONS

The three-rod distortable ferrule design requires aligning rods having identical material uniformity and diameter. The aligning rods must be sufficiently rigid to eliminate axial distortion, when abutted, but pliable enough to be positioned by an elastomeric hourglass alignment sleeve. After extensive investigation, it was concluded that attainment of sufficient material uniformity in plastics, either in their modulus diameter or in their diameter, was not sufficient to achieve the alignment necessary for a 1.0 - 1.5 dB interconnection, or stable enough to prevent creepage which results in fiber breakage. It was recommended, and accepted, that the three-rod design work be discontinued and replaced with a three-sphere design which is not subject to material non-uniformity problems.

Investigations to date on the three-sphere ferrule design indicate that the aligning spheres must be undersize in order to insure positive clamping of the fiber, thereby eliminating lateral misalignment due to fiber diameter variations. A method for improving fiber-ferrule axial concentricity to eliminate cantilever lateral misalignment is required. It has been found that ferruled fibers are damaged by direct impingement of moderate velocity sand and dust particles on the fiber end face. It has also been found that no damage occurs due to 10 g vibrational stress in the frequency range from 10 to 500 Hz. It is recommended that (1) a protective shield be incorporated into the connector design to eliminate sand and dust damage, (2) an additional row of alignment spheres be incorporated into each ferrule to insure proper axial fiber alignment, and (3) a method of cleaning fibers to provide mating surfaces with axially perpendicular ends be developed.

FIGURE 1

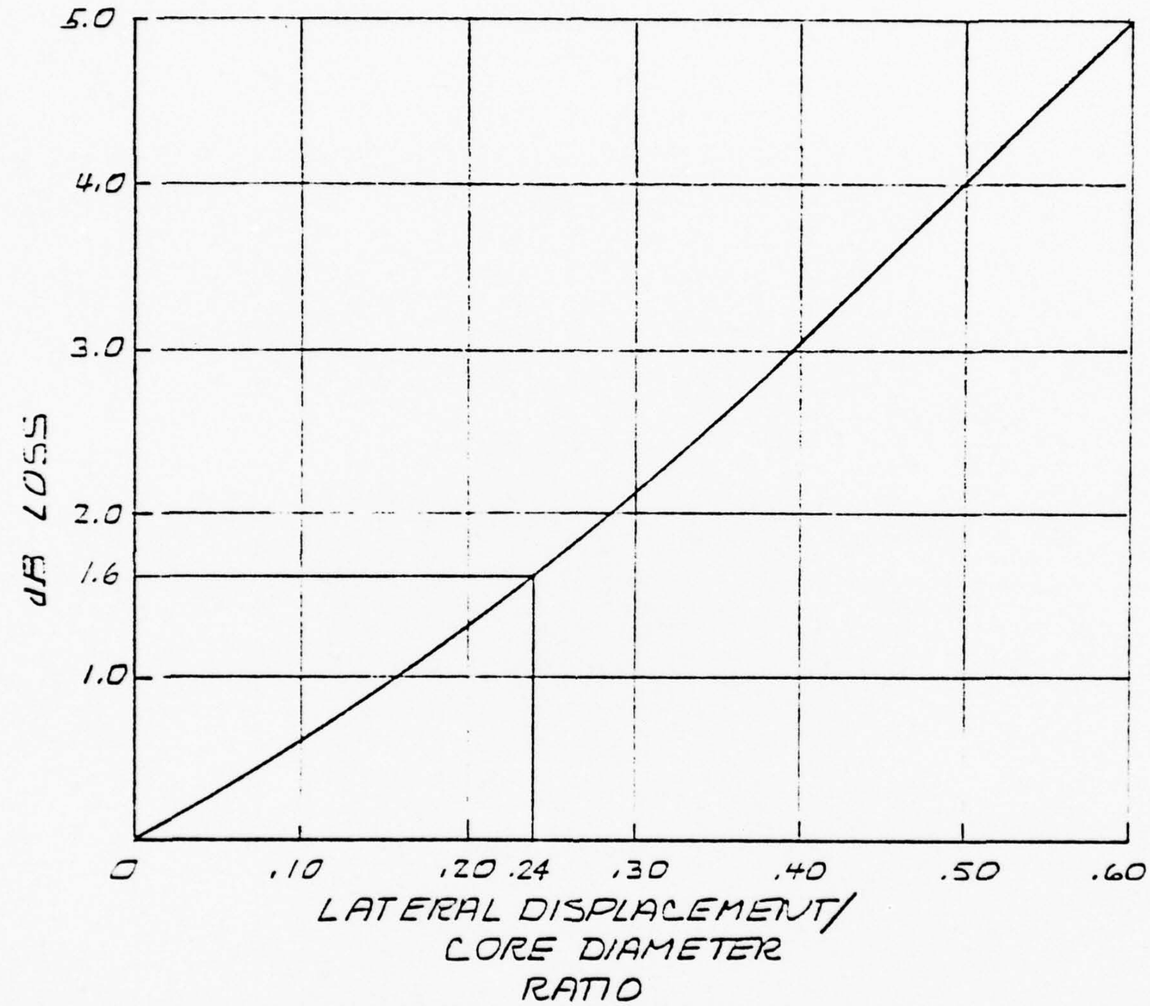
ITT CANNON ELECTRIC
9-22-77



JEWELED FERRULE ALIGNMENT ANALYSIS

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

FIGURE 2



REFERENCE	INTENDED USE	PART NUMBER

DIMENSIONS IN INCHES, TOLERANCES FOR DECIMALS AND ANGLES AS SHOWN DO NOT SCALE	DRAWN James	6/12/77	ITT CANNON ELECTRIC 3208 Humboldt Street, Los Angeles, Calif. 90031 A Division of International Telephone and Telegraph Corporation
MATERIAL	CHECKED R McCartney	6/12/77	OPTICAL LOSS VS LATERAL DISPLACEMENT
FINISH	APPROVED		
TREATMENT	APPROVED		SIZE A · CODE IDENT. NO. 71468
			SCALE · WT. · SHEET

CEC255A HQ (REV. 6-66)

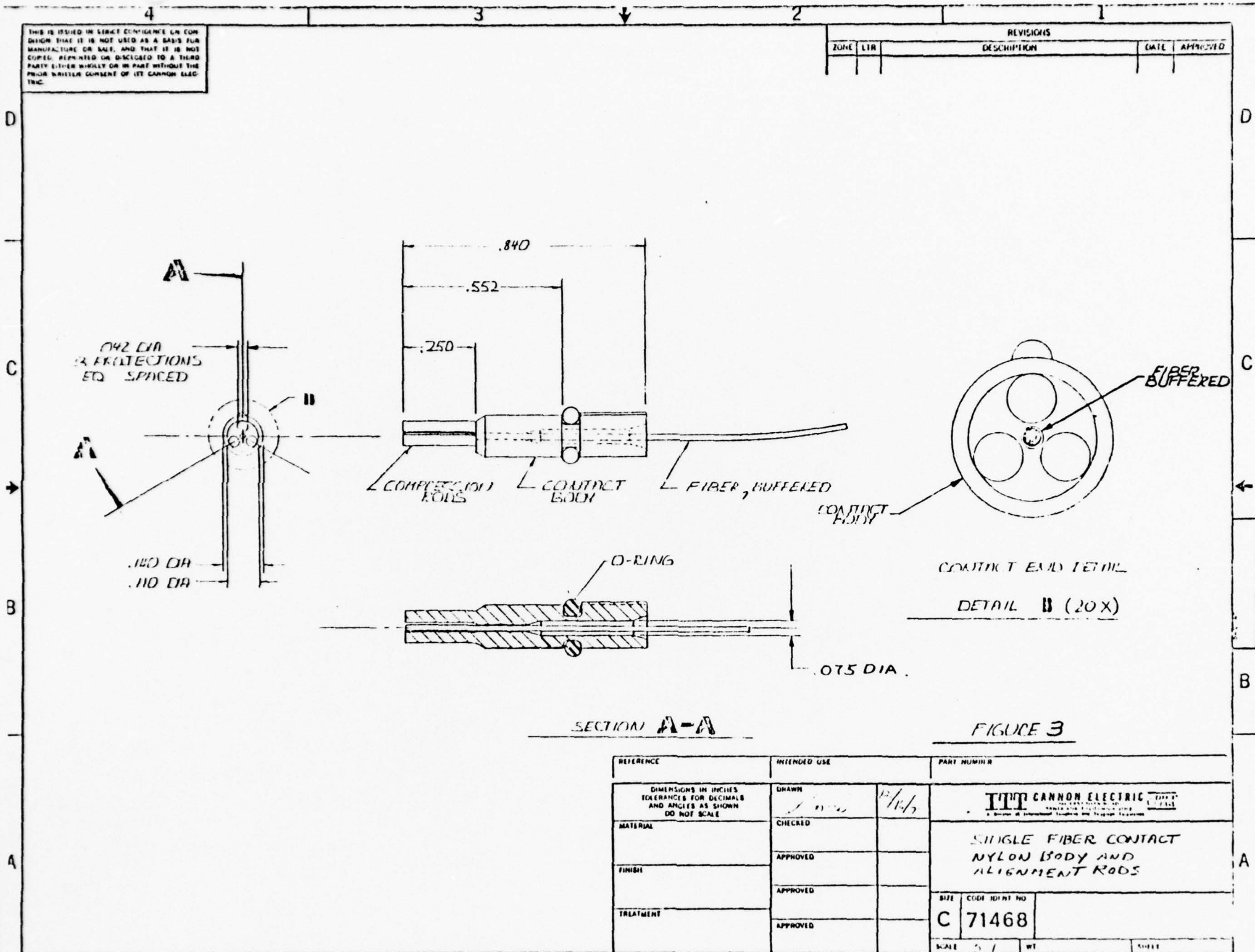
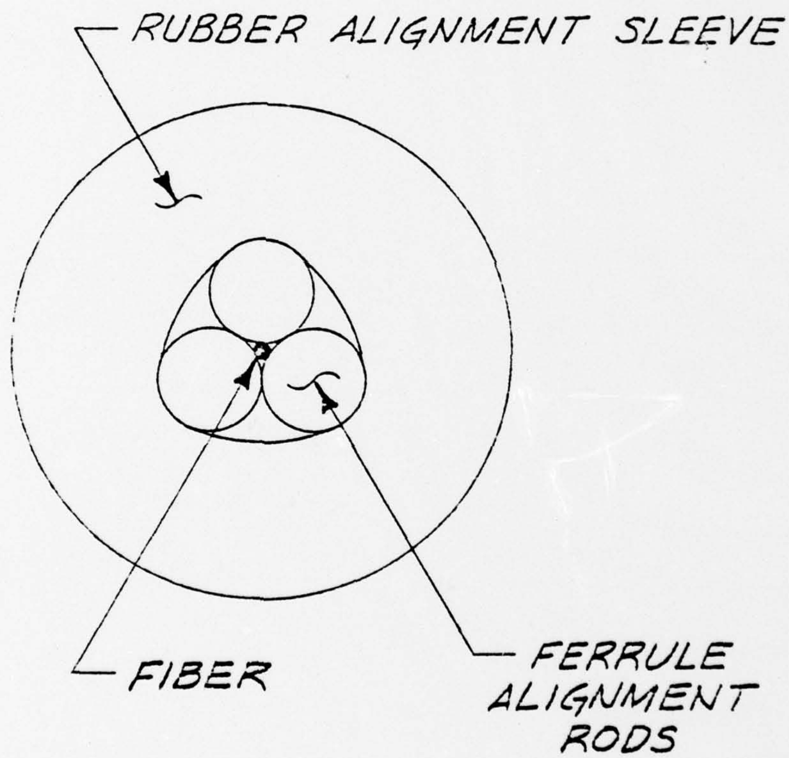
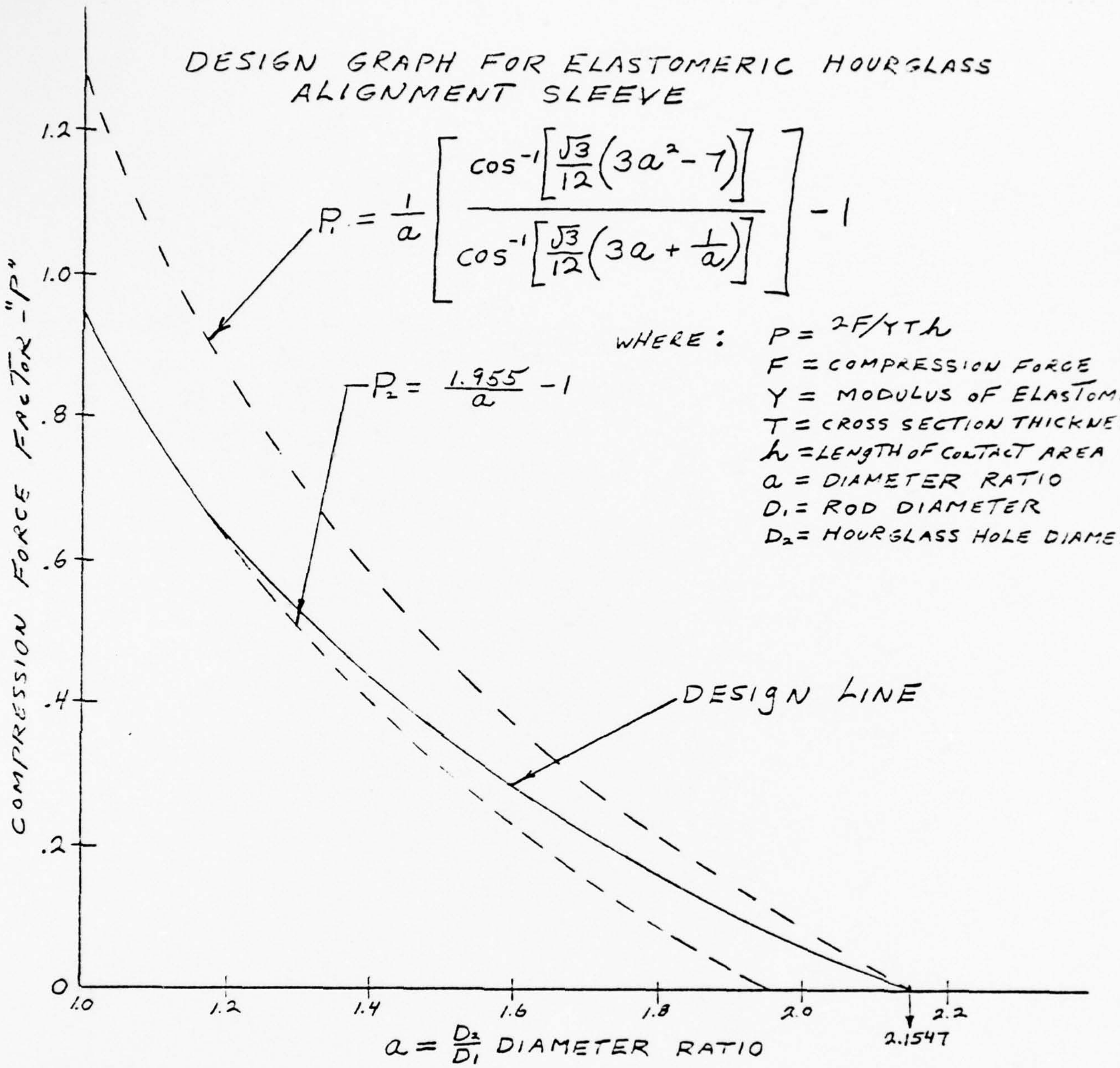

THIS IS ISSUED IN STRICT CONFIDENCE ON CONDITION THAT IT IS NOT USED AS A BASIS FOR MANUFACTURE OR SALE, AND THAT IT IS NOT COPIED, REPRINTED OR DISCLOSED TO A THIRD PARTY EITHER WHOLLY OR IN PART WITHOUT THE PRIOR WRITTEN CONSENT OF ITT CANNON ELECTRIC.
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
A
.042 DIA
3 PROJECTIONS
EQ SPACED
B
.140 DIA
.110 DIA
.840
.552
.250
COMPRESSION RODS
CONTACT BODY
FIBER, BUFFERED
O-RING
.075 DIA.
SECTION A-A
FIBER BUFFERED
CONTACT BODY
CONTACT END DETAIL
DETAIL B (20X)
REFERENCE
INTENDED USE
PART NUMBER
DIMENSIONS IN INCHES TOLERANCES FOR DECIMALS AND ANGLES AS SHOWN DO NOT SCALE
MATERIAL
FINISH
TREATMENT
DRAWN
CHECKED
APPROVED
ITT CANNON ELECTRIC
SINGLE FIBER CONTACT
NYLON BODY AND
ALIGNMENT RODS
SIZE
C
CODE IDENT NO
71468
SCALE
WT
SHEET

FIGURE 3

FIGURE 4

RUBBER ALIGNMENT SLEEVE AND
3 RODS COMPRESSED AROUND FIBER





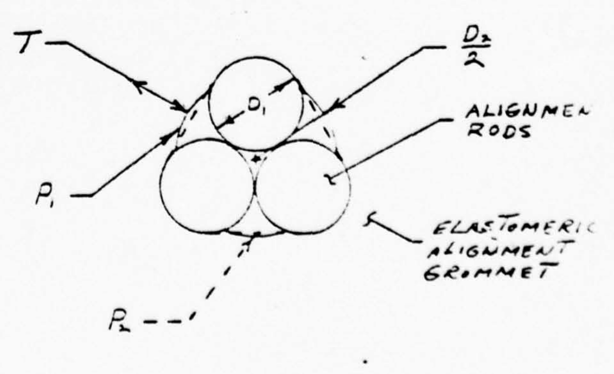


FIGURE 5

ITT CANNON ELECTRIC
6-24-77

NYLON THREE ROD FERRULE OPTICAL LOSS WITHOUT AXIAL LOADING IN SIX CHANNEL CONNECTOR

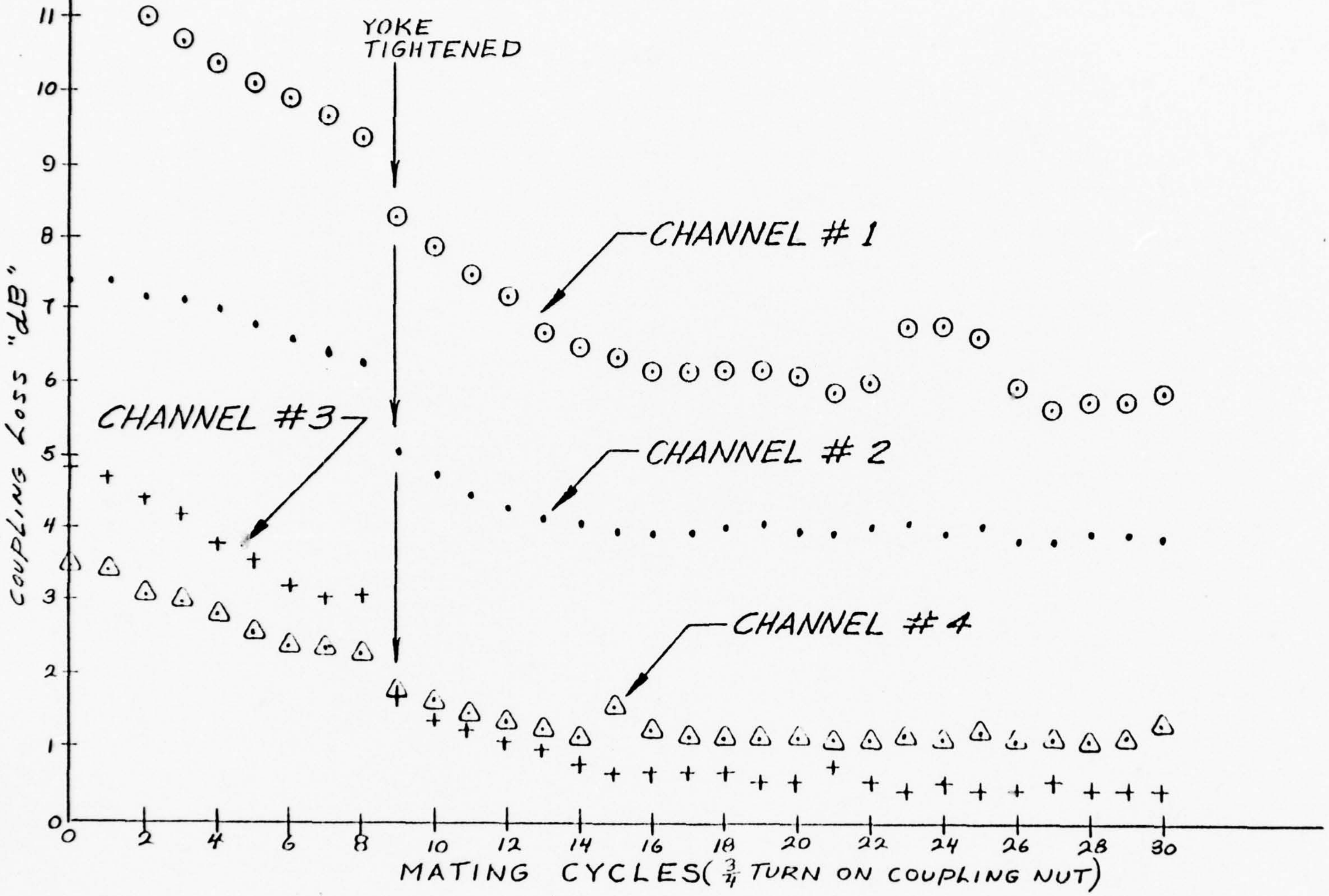


FIGURE 6

ITT CANNON ELECTRIC 6-24-77

RIGID THREE ROD FERRULE COUPLING LOSS CHARACTERISTICS
WITH AXIAL LOADING

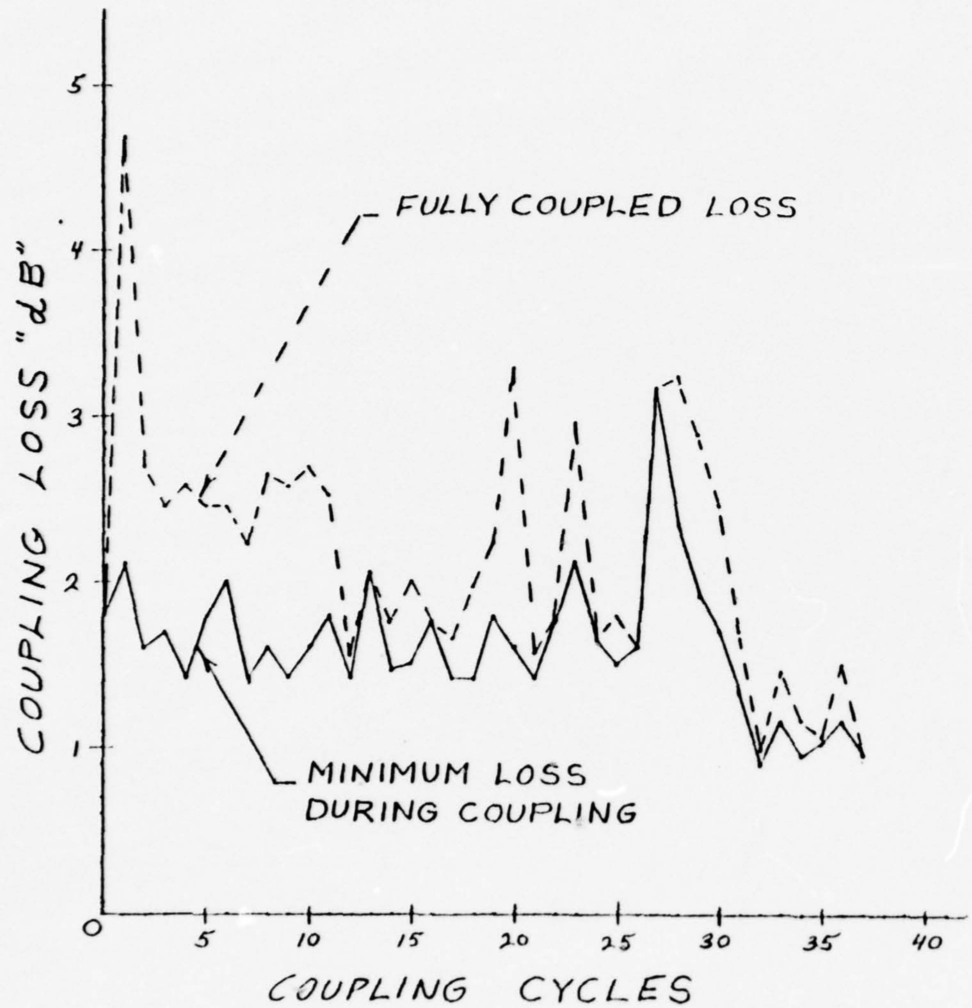


FIGURE 7

ITT CANNON ELECTRIC
6-27-77

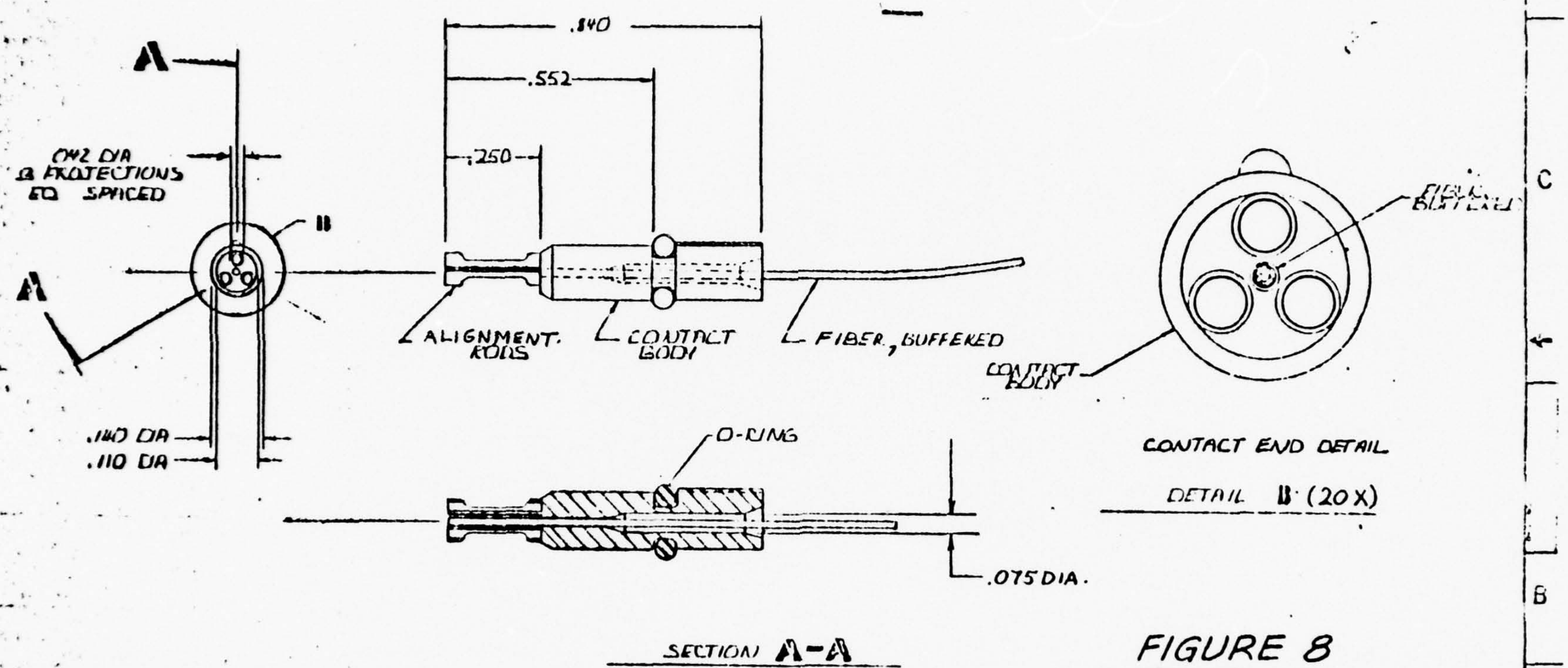


FIGURE 8

REFERENCE	INTENDED USE	PART NUMBER
DIMENSIONS IN INCHES TOLERANCES FOR DECIMALS AND ANGLES AS SHOWN DO NOT SCALE	DRAWN J. James 12/14/78	ITT CANNON ELECTRIC
MATERIAL	CHECKED	SINGLE FIBER CONTACT REDUCED ALIGNMENT ROD CROSS SECTION
FINISH	APPROVED	
TREATMENT	APPROVED	SIZE C CODE IDENT NO 71468
	APPROVED	SCALE 5/1 WT. SHEET

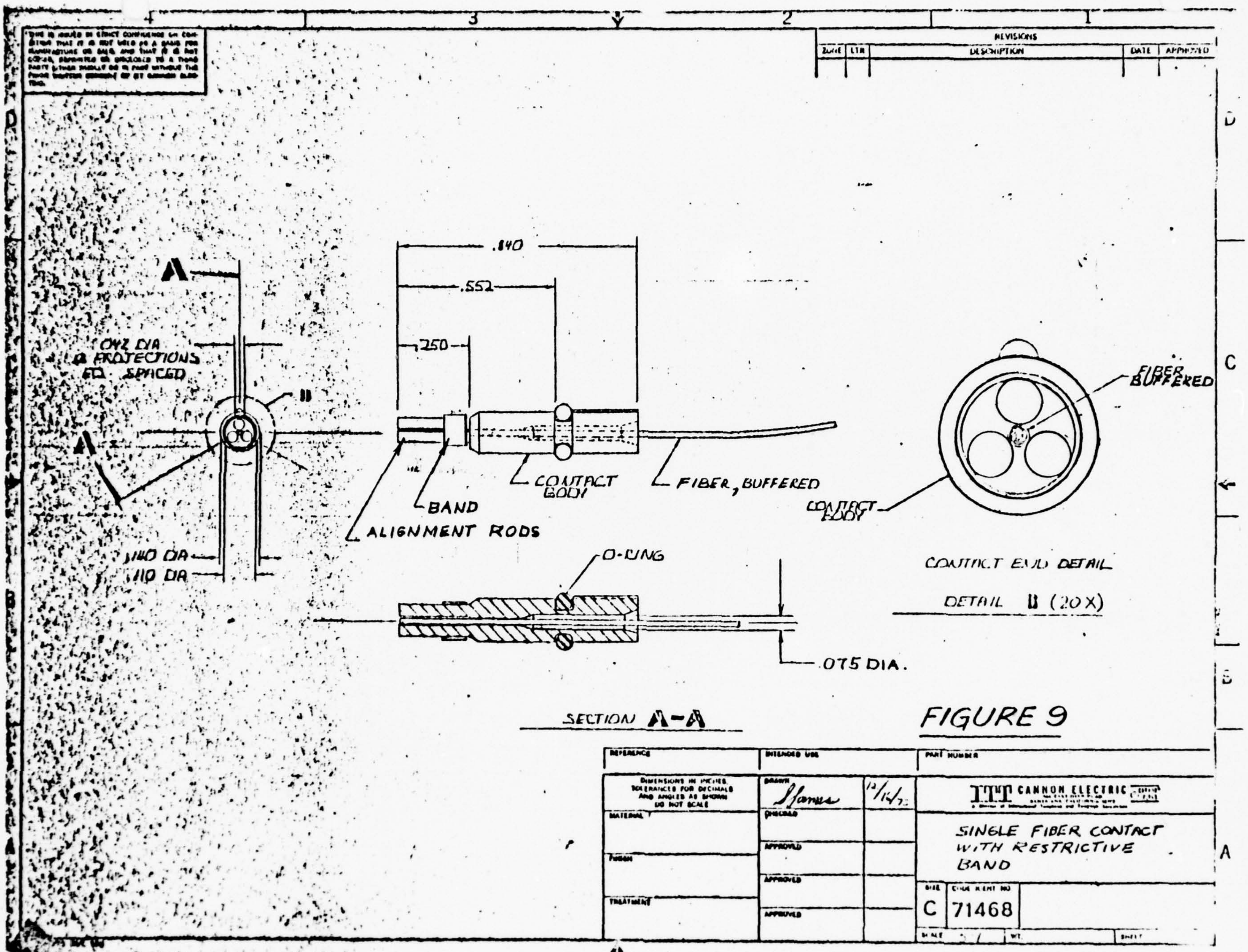
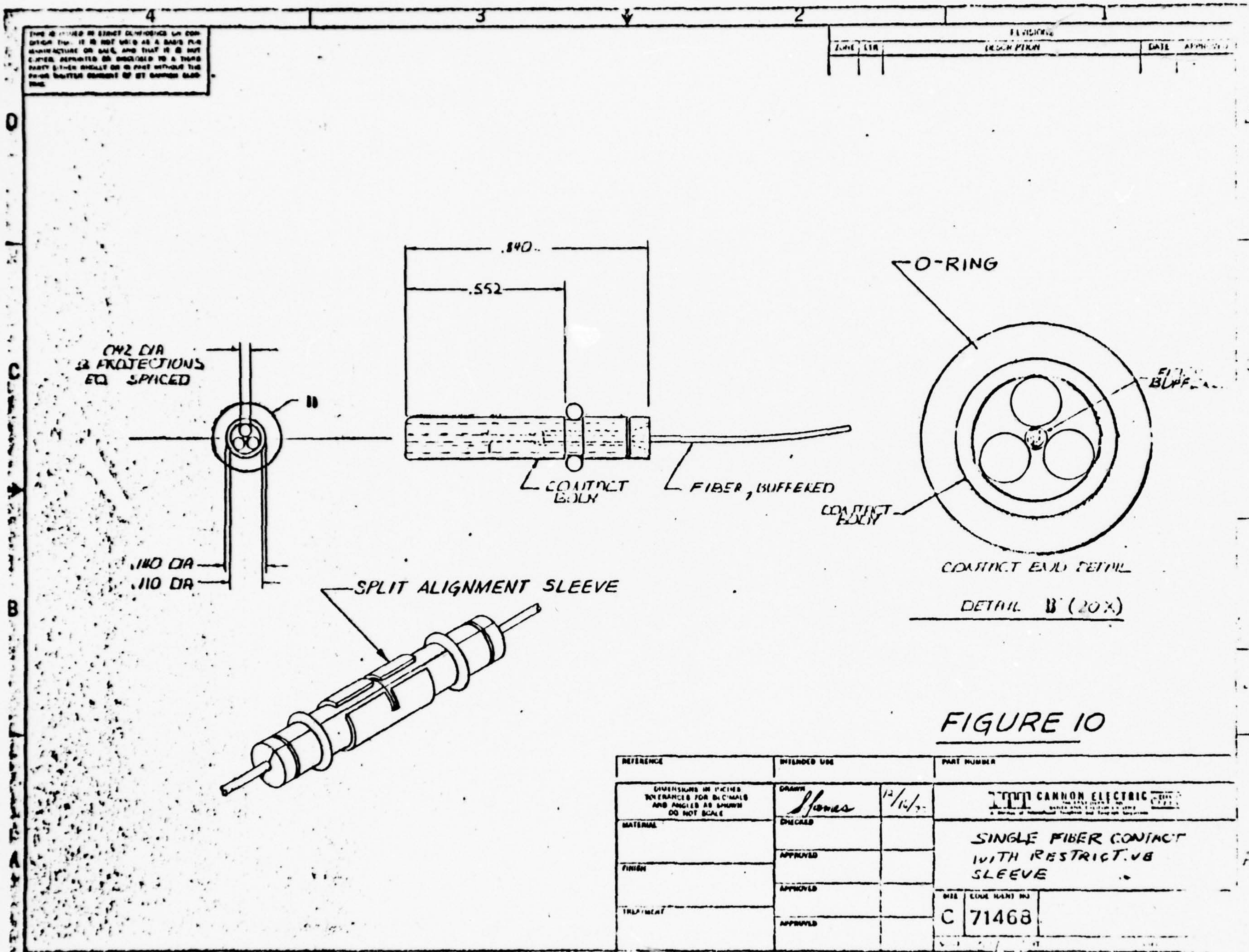
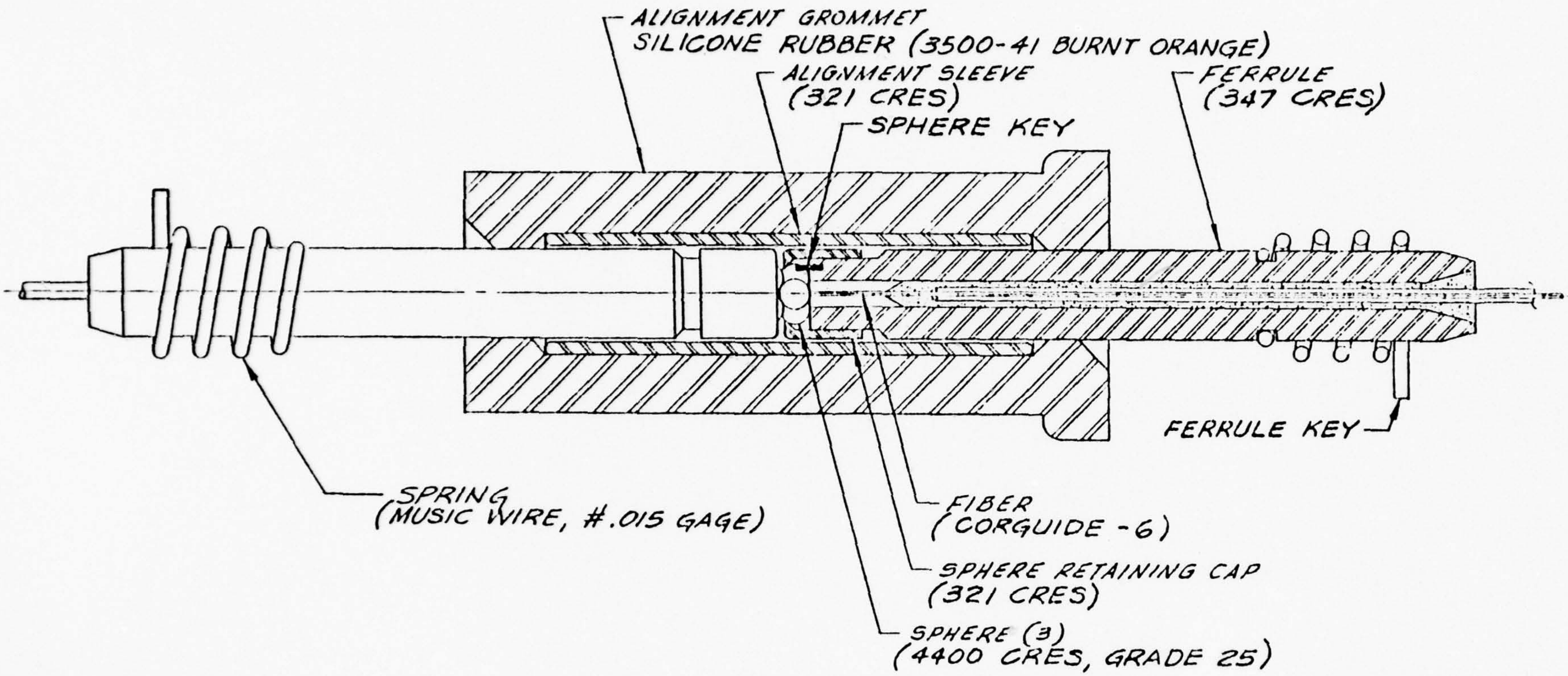

REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
A-A
.042 DIA
3 PROJECTIONS EQ. SPACED
B
.140 DIA
.110 DIA
.840
.552
.250
ALIGNMENT RODS
BAND
CONTACT BODY
FIBER, BUFFERED
O-RING
.075 DIA.
SECTION A-A
FIBER BUFFERED
CONTACT BODY
CONTACT END DETAIL
DETAIL B (20X)
DIMENSIONS IN INCHES TOLERANCES FOR DECIMALS AND ANGLES AS SHOWN DO NOT SCALE
ITT CANNON ELECTRIC
SINGLE FIBER CONTACT WITH RESTRICTIVE BAND
C 71468

FIGURE 9



.042 DIA
3 PROJECTIONS
EQ SPACED
B
.110 DIA
.110 DIA
.840
.552
CONTACT BODY
FIBER, BUFFERED
SPLIT ALIGNMENT SLEEVE
O-RING
CONTACT BODY
CONTACT END DETAIL
DETAIL B (20X)
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
REFERENCE
INTENDED USE
PART NUMBER
DIMENSIONS IN INCHES
TOLERANCES FOR DECIMALS AND ANGLES AS SHOWN
DO NOT SCALE
MATERIAL
FINISH
TREATMENT
DRAWN
CHECKED
APPROVED
ITT CANNON ELECTRIC
SINGLE FIBER CONTACT
WITH RESTRICTIVE
SLEEVE
C
71468

FIGURE 10



THREE SPHERE FIXED KEYED FERRULE

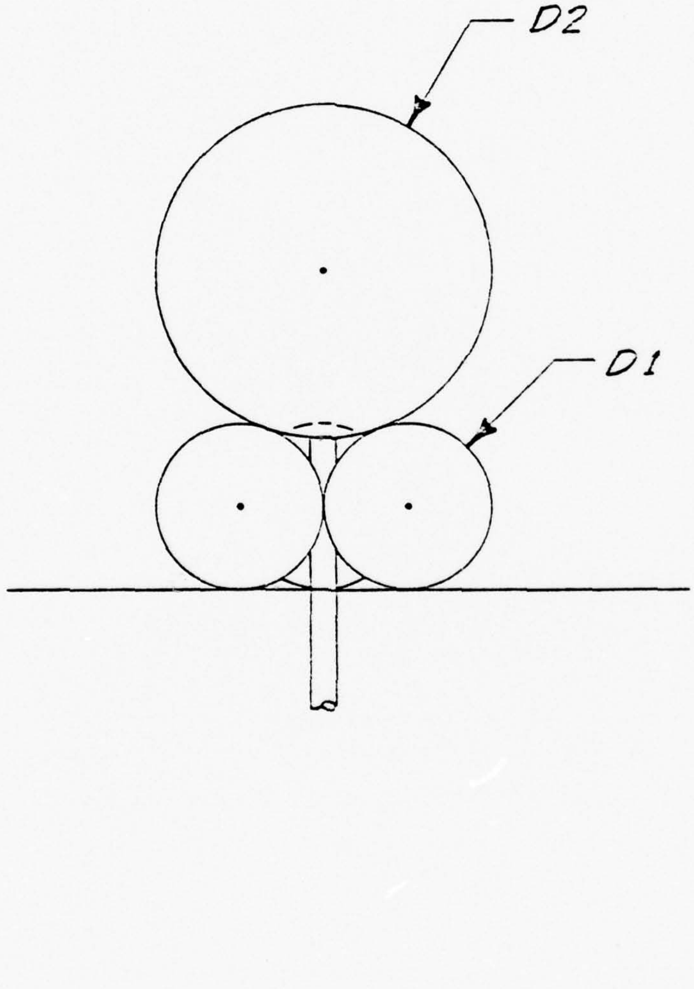
FIGURE 11

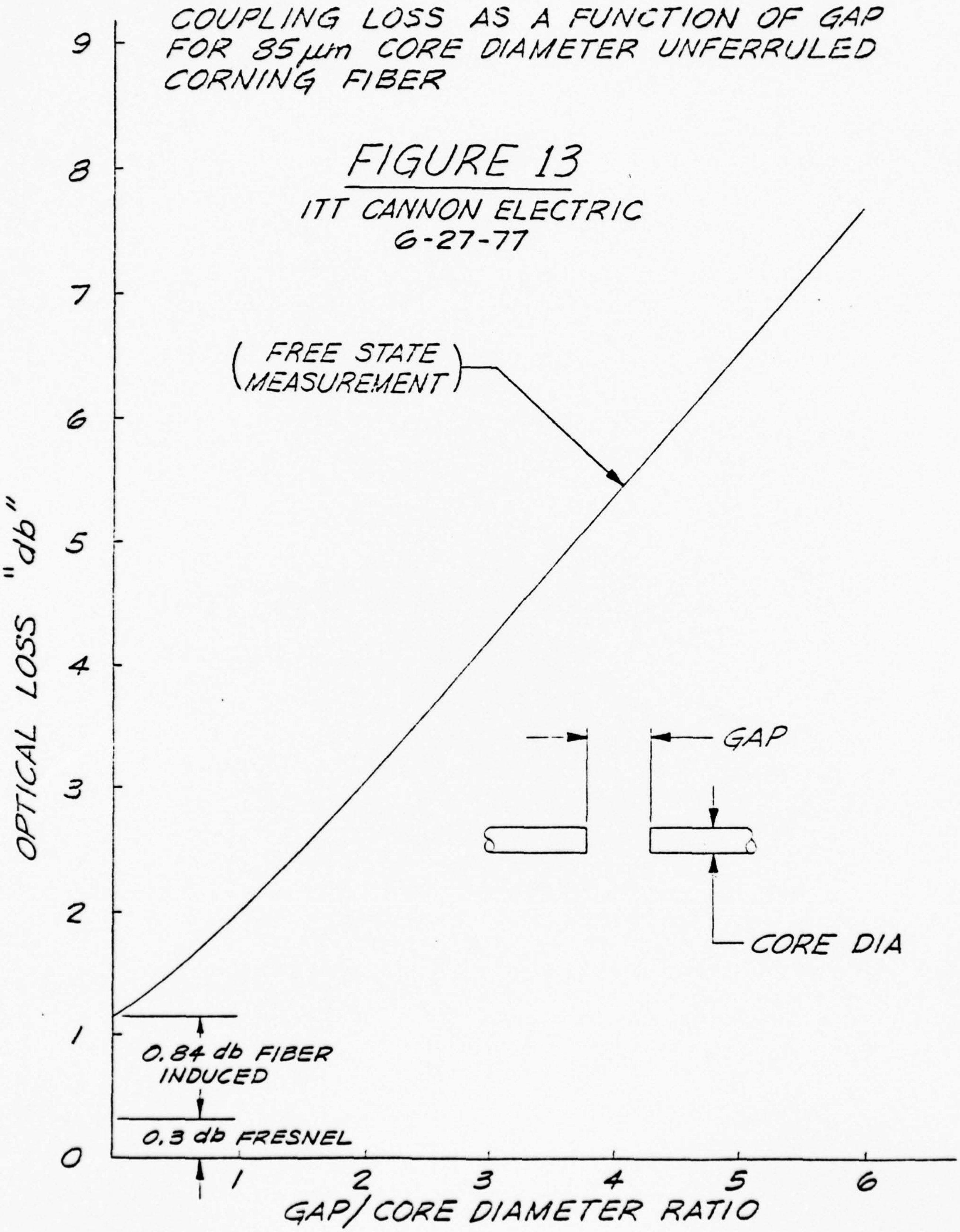
ITT CANNON ELECTRIC

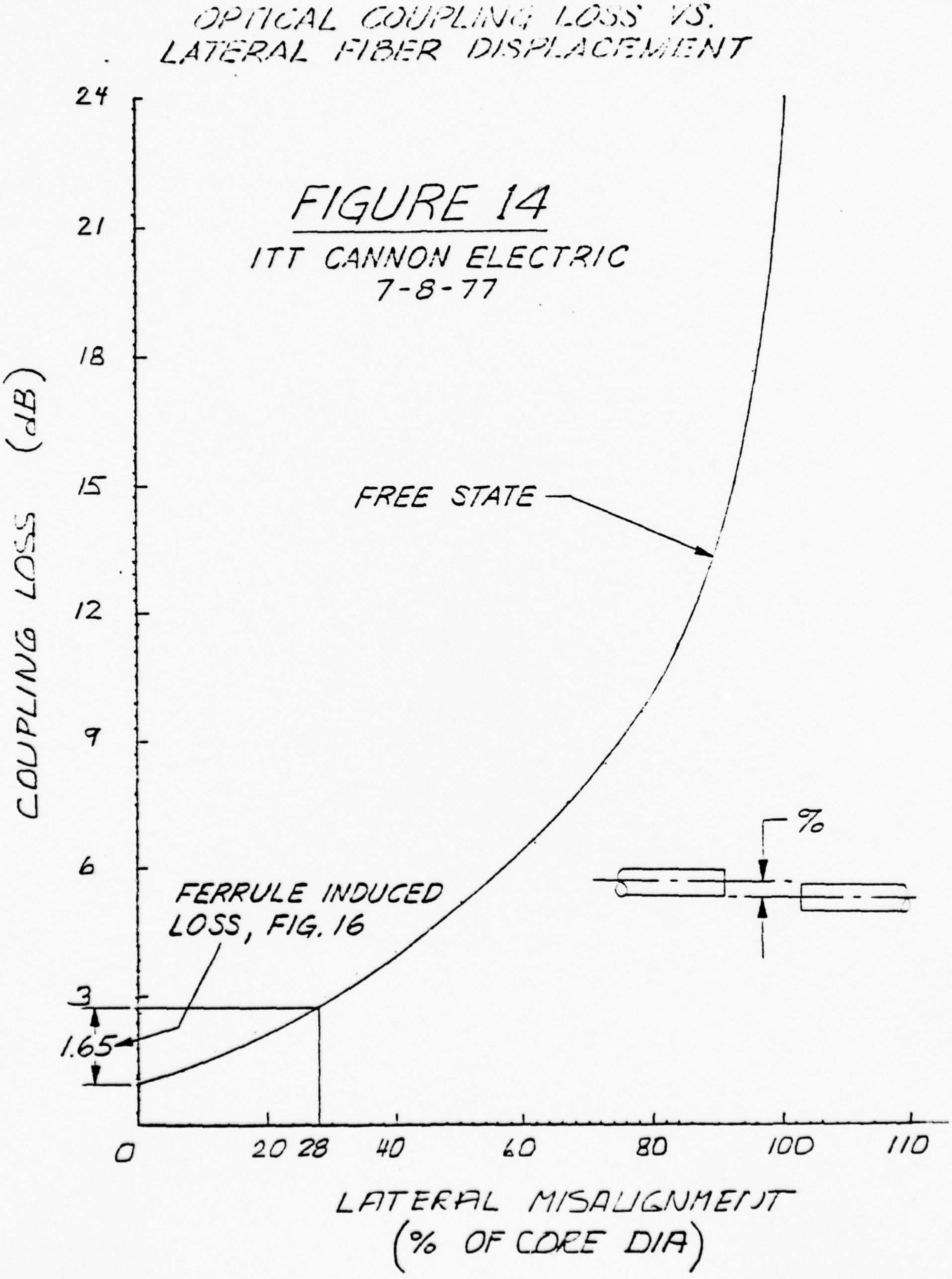
FORTH SPHERE FIBER
AXIAL POSITIONER

FIGURE 12

ITT CANNON ELECTRIC
7-8-77



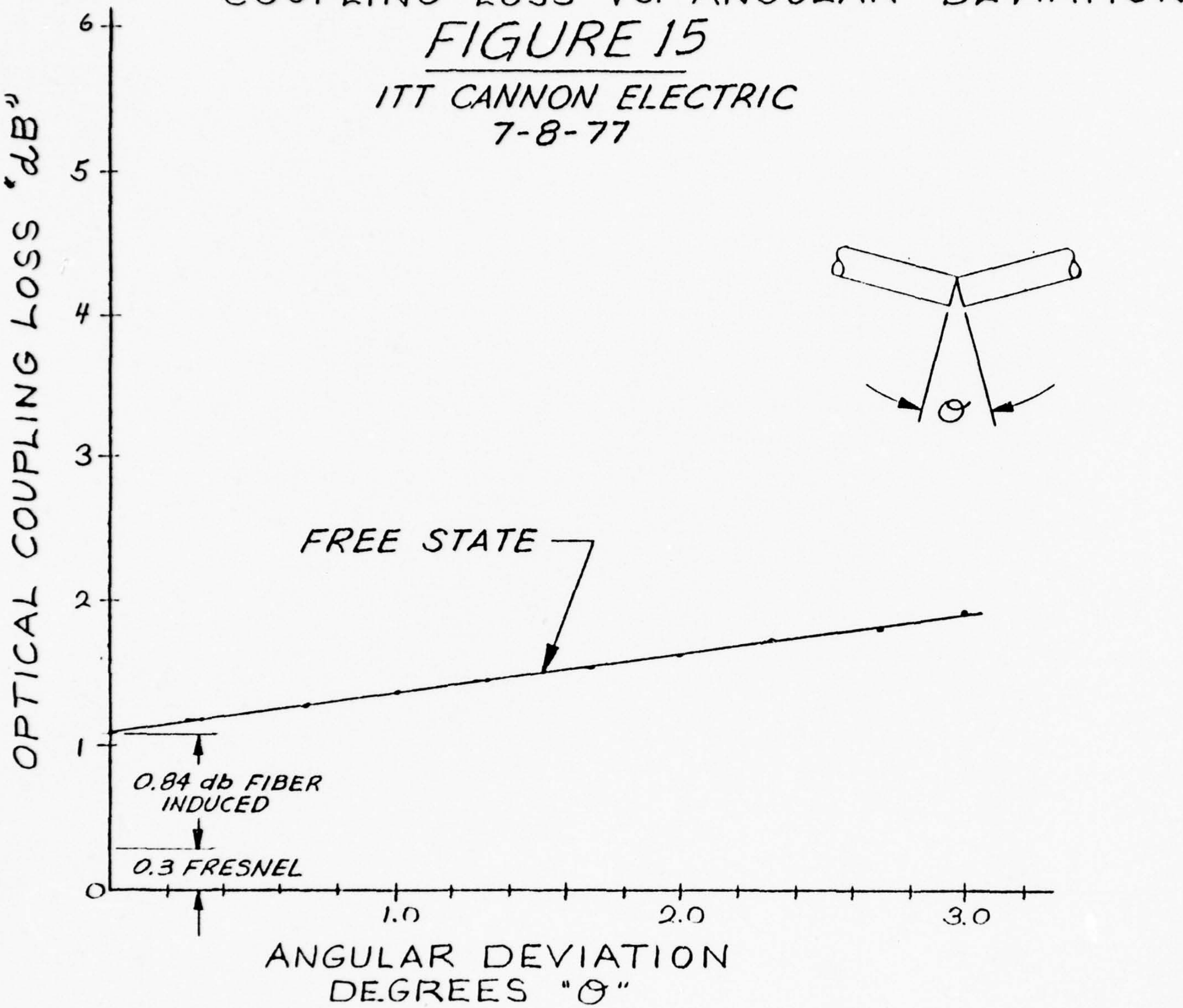

COUPLING LOSS AS A FUNCTION OF GAP
FOR 85 μm CORE DIAMETER UNFERRULED
CORNING FIBER
FIGURE 13
ITT CANNON ELECTRIC
6-27-77
FREE STATE
MEASUREMENT
GAP
CORE DIA
0.84 db FIBER
INDUCED
0.3 db FRESNEL
OPTICAL LOSS "db"
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
GAP/CORE DIAMETER RATIO


OPTICAL COUPLING LOSS VS.
LATERAL FIBER DISPLACEMENT
FIGURE 14
ITT CANNON ELECTRIC
7-8-77
COUPLING LOSS (dB)
24
21
18
15
12
9
6
3
1.65
FREE STATE
FERRULE INDUCED LOSS, FIG. 16
%
0
20
28
40
60
80
100
110
LATERAL MISALIGNMENT
(% OF CORE DIA)

COUPLING LOSS VS. ANGULAR DEVIATION

FIGURE 15

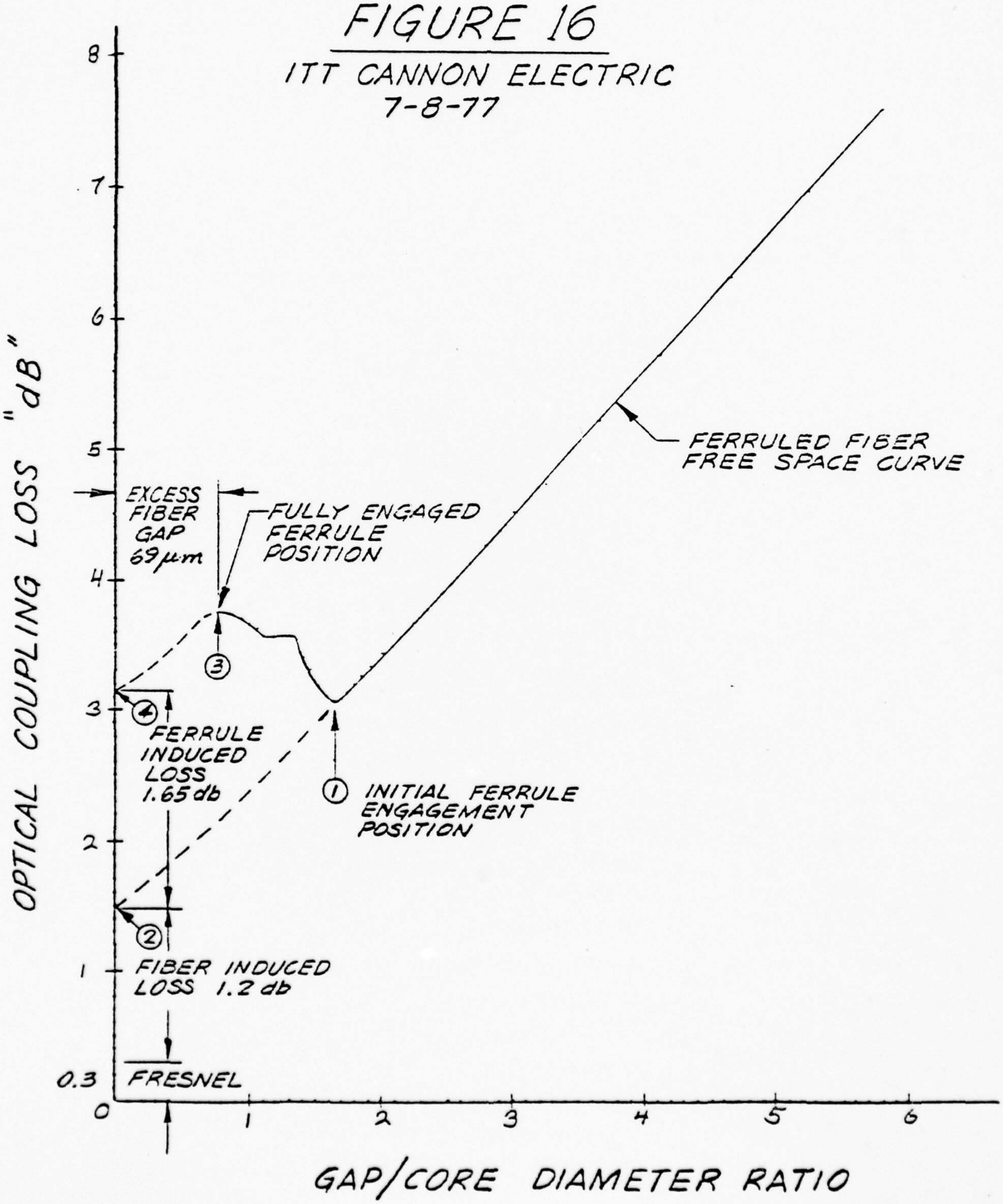
ITT CANNON ELECTRIC
7-8-77



THREE SPHERE KEYED FERRULE COUPLING LOSS

FIGURE 16

ITT CANNON ELECTRIC
7-8-77



TEMPERATURE CYCLE CONNECTOR EVALUATION
(ROOM TEMP COUPLING LOSS REF LEVEL = 0.0 dB)

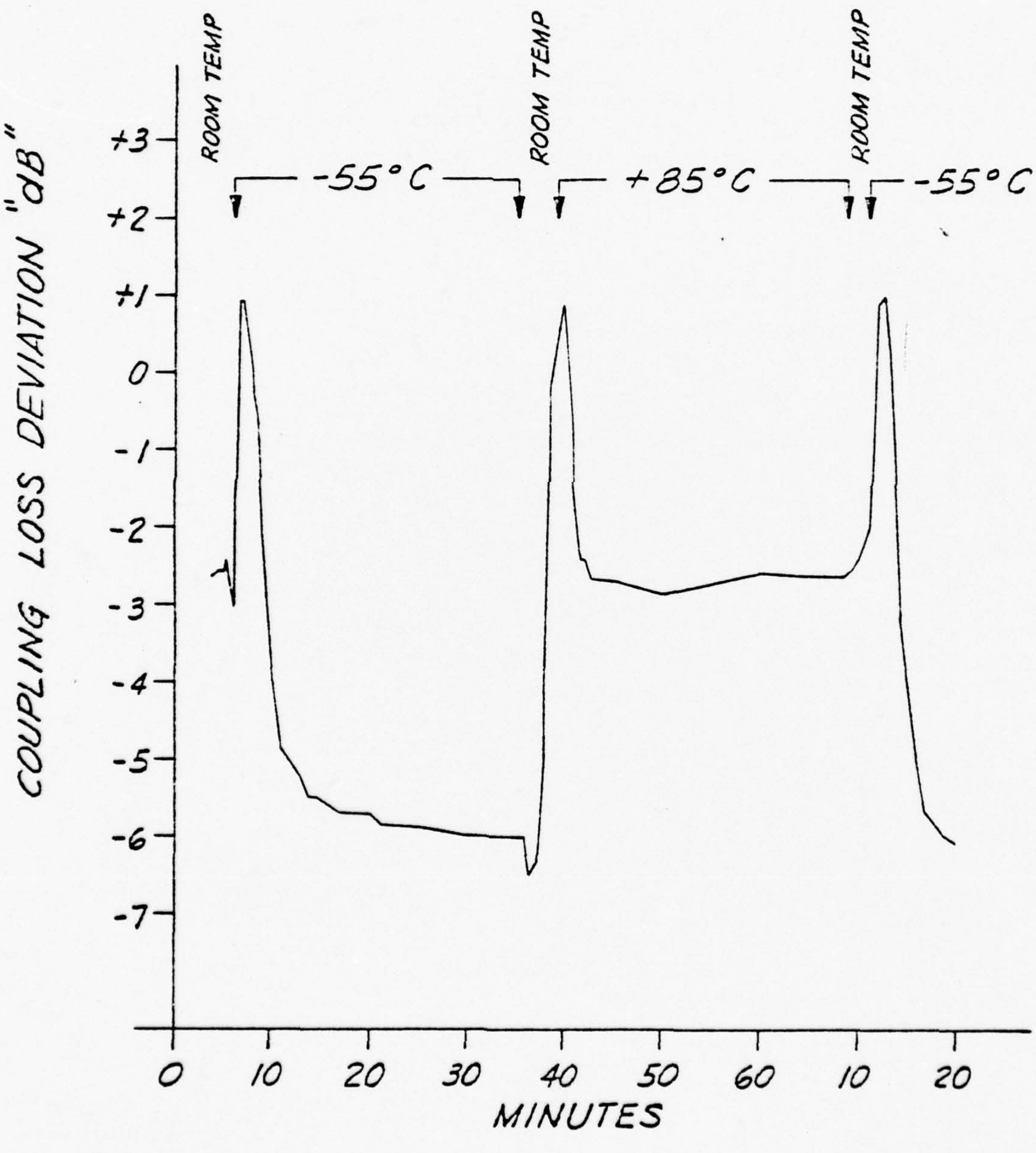
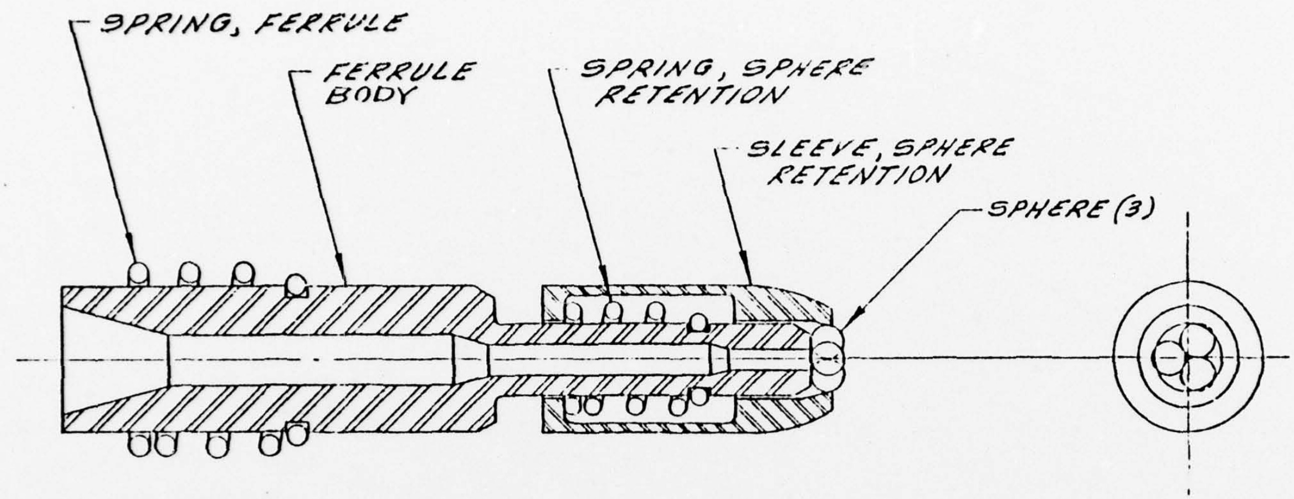


FIGURE 17

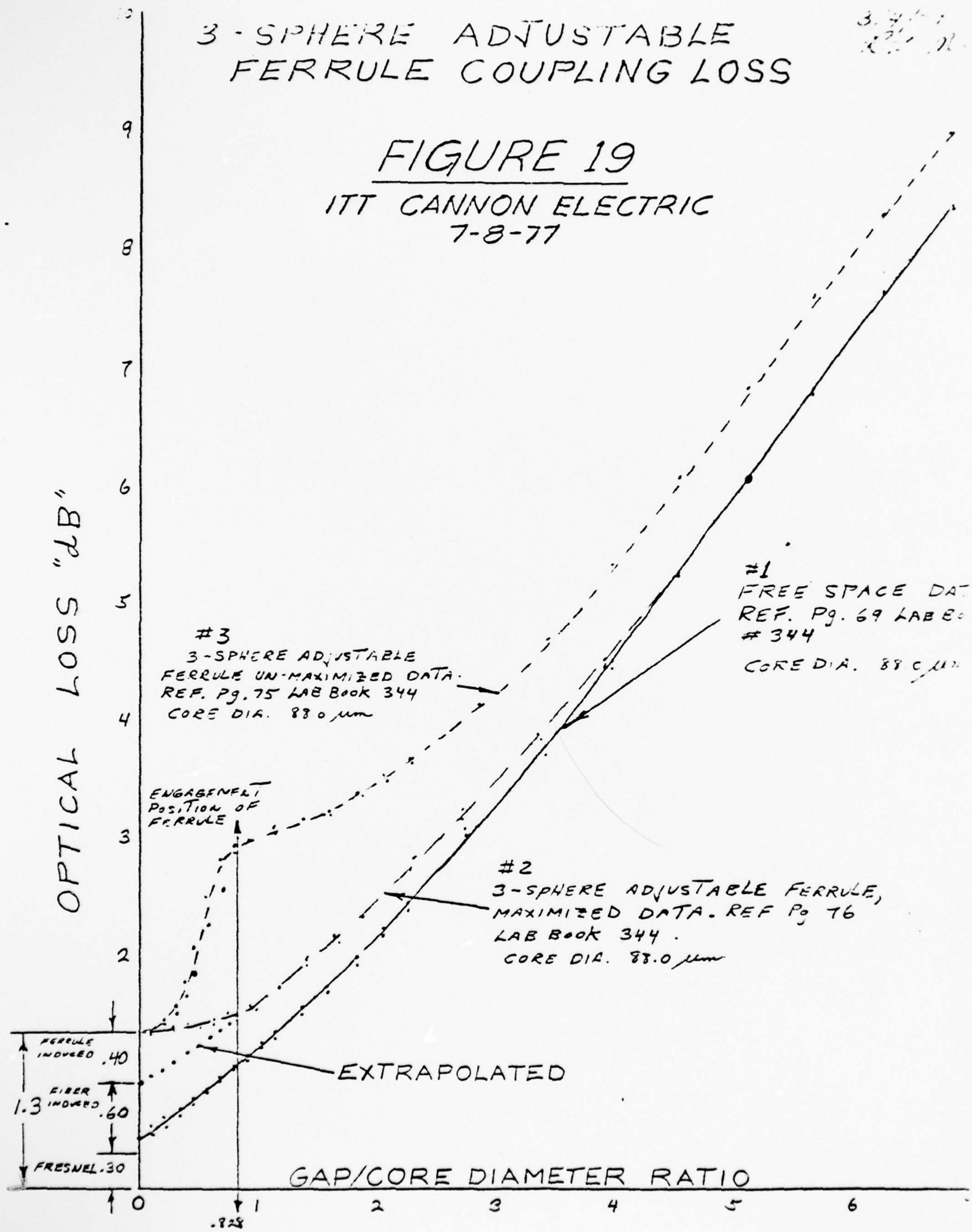
ITT CANNON ELECTRIC
7-8-77



THREE SPHERE, ADJUSTABLE FERRULE

FIGURE 18

ITT CANNON ELECTRIC
6-29-77

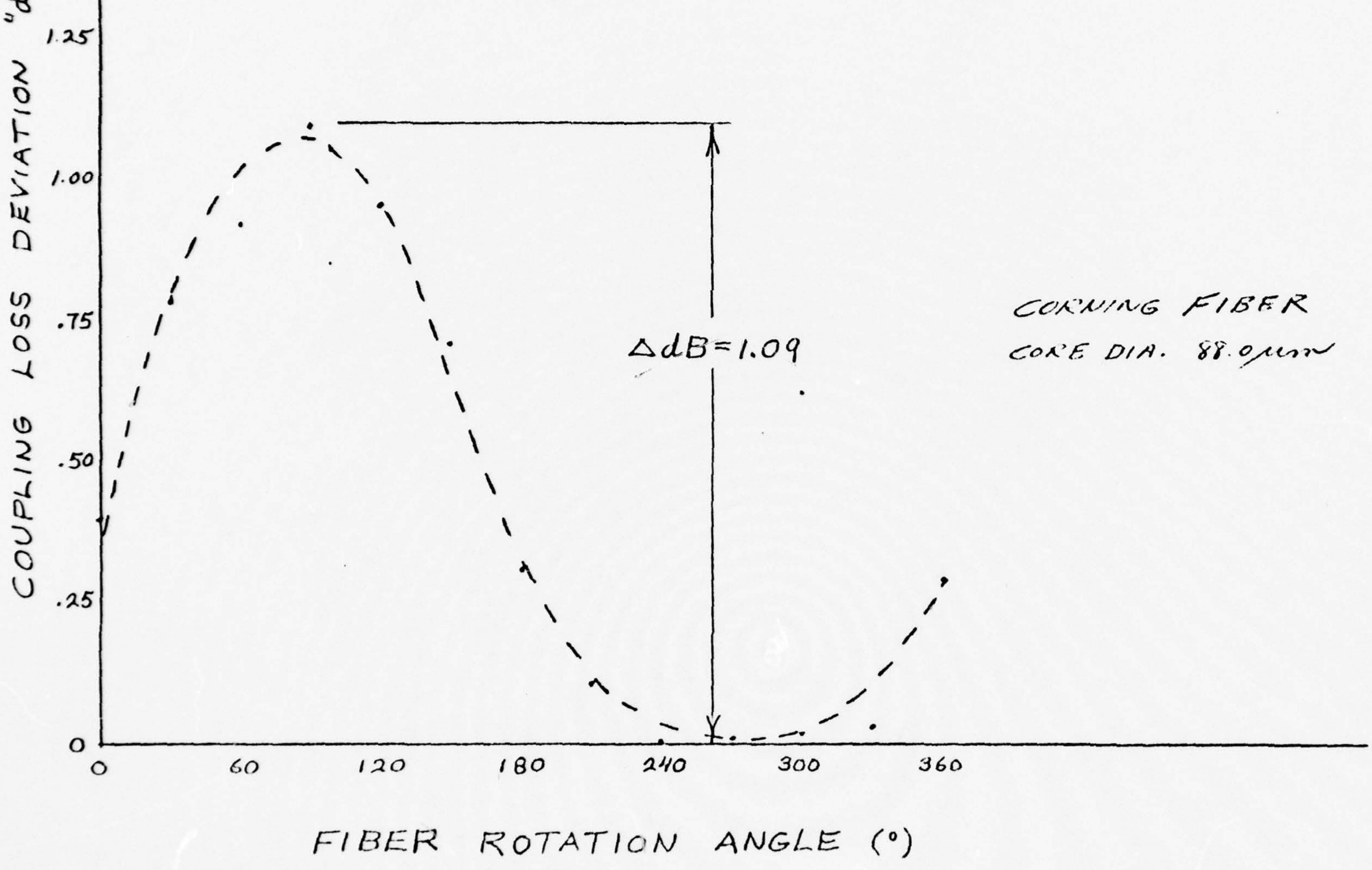


3-SPHERE ADJUSTABLE
FERRULE COUPLING LOSS
FIGURE 19
ITT CANNON ELECTRIC
7-8-77
OPTICAL LOSS "dB"
GAP/CORE DIAMETER RATIO
#1
FREE SPACE DAT
REF. Pg. 69 LAB
#344
CORE DIA. 88 μm
#3
3-SPHERE ADJUSTABLE
FERRULE UN-MAXIMIZED DATA.
REF. Pg. 75 LAB Book 344
CORE DIA. 88.0 μm
#2
3-SPHERE ADJUSTABLE FERRULE,
MAXIMIZED DATA. REF Pg 76
LAB Book 344.
CORE DIA. 88.0 μm
ENGAGEMENT
POSITION OF
FERRULE
EXTRAPOLATED
FERRULE INDUCED .40
FIBER INDUCED .60
1.3
FRESNEL .30
.828
0
1
2
3
4
5
6
7
8
9

FREE SPACE COUPLING LOSS AS A FUNCTION OF ROTATION ANGLE

FIGURE 20

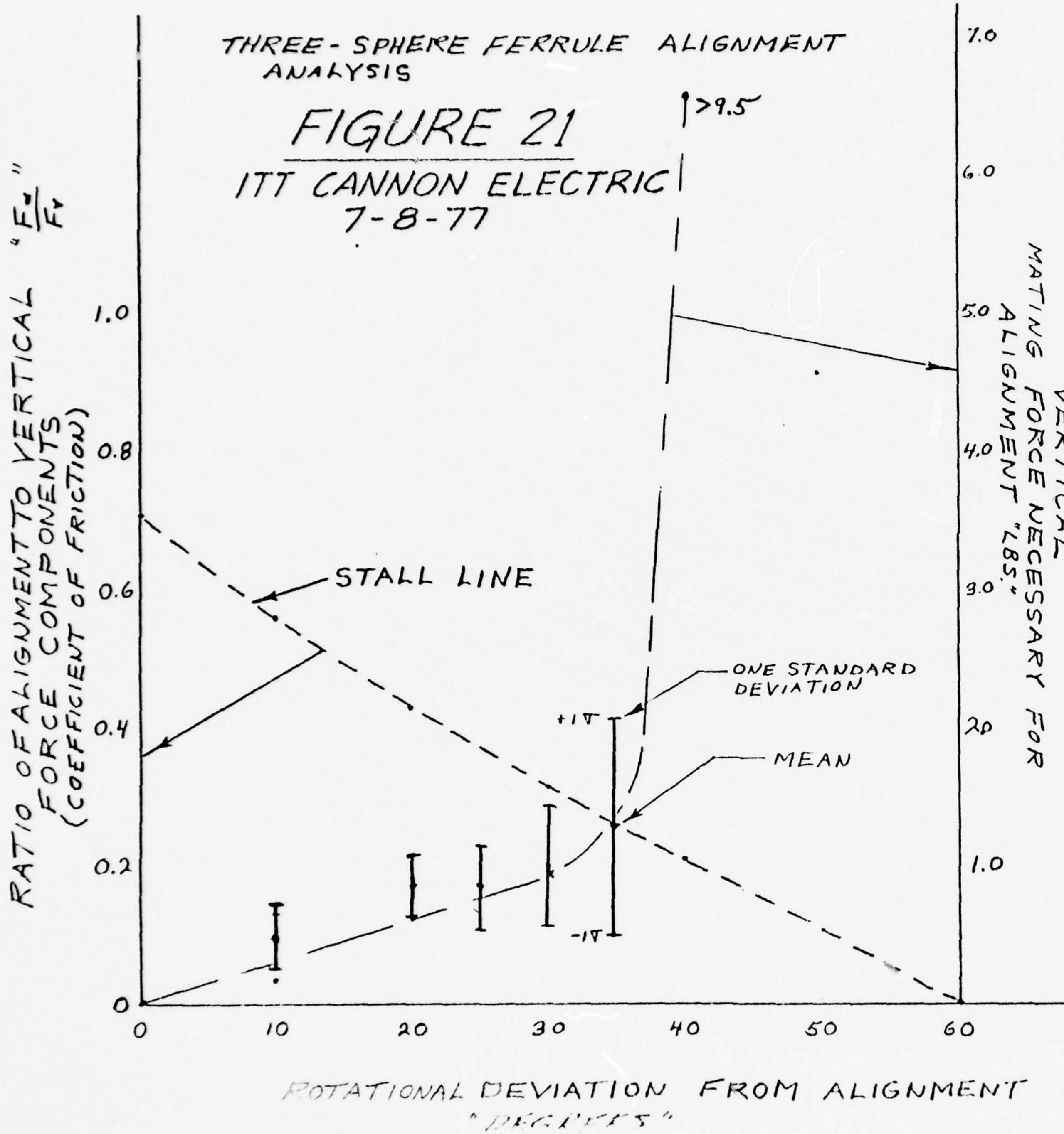
ITT CANNON ELECTRIC
7-8-77



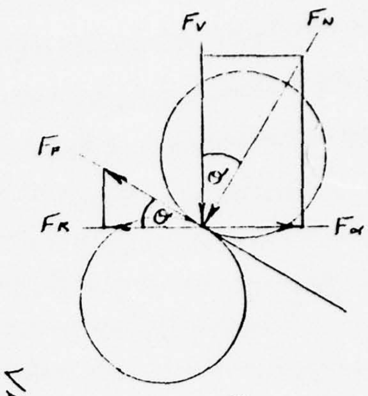
THREE-SPHERE FERRULE ALIGNMENT ANALYSIS

FIGURE 21

ITT CANNON ELECTRIC
7-8-77



8/30/77
R.J.M.



$$\sin\alpha = \frac{F_\alpha}{F_N}$$

$$F_F = K F_N$$

$$F_R = F_F \cos\alpha$$

WHEN $F_R = F_\alpha$ THE FERRULE WILL STALL.

$$K F_N \cos\alpha = F_N \sin\alpha$$

$$K = \tan\alpha$$

WHERE:

$K \Rightarrow$ COEFF. OF FRICTION
$F_\alpha \Rightarrow$ ALIGNMENT FORCE
$F_V \Rightarrow$ VERTICAL MATING FORCE
$F_N \Rightarrow$ NORMAL FORCE
$F_F \Rightarrow$ FRICTIONAL FORCE
$F_R \Rightarrow$ RESTRAINING FORCE
$\alpha \Rightarrow$ ENGAGEMENT ANGLE

APPENDIX A

BALLS, CUSTOM MADE

BALLS are custom made locally by Bal-tec™

Bal-tec (213) 582-7348

A DIVISION OF MICRO SURFACE ENGR., INC.
1550 E. Slauson Avenue
Los Angeles, CA 90011

#1 Last year Bal-tec Div.* delivered 93% of all ball orders within three days.

#2 Bal-tec will custom manufacture special balls of any workable material.

#3 We can manufacture balls from under .020" diameter to over 17" diameter to any exact size needed.

#4 There is NO minimum quantity requirements. We can make a single ball, if that is the most economical solution to your problem.

#5 We are a well established company with over two decades of experience in manufacturing special custom made balls.

#6 We maintain a large inventory of overruns on previous special orders, and carry a full inventory of standard fractional sizes. The special ball you need, may be in stock right now.

#7 Both our manufacturing plant and warehouse facilities are located in the central Los Angeles area, for the fastest possible service to the west.

#8 Because we process many small orders at the same time, the cost of our custom made balls is very reasonable.

#9 The quality of our product is protected by the finest metrology department with the most up to date equipment in the in the industry today.

Technical Data on Balls - - see other side

* Trade mark of Micro Surface Engr., Inc.

CHROME ALLOY STEEL BALLS-are the most common bearing alloy. They are mfg. from high grade steel of the through hardening type, conforming to AISI E-52100. The balls are properly heat-treated, free of surface decarburization.

CORROSION RESISTING HARDENED BALLS-are mfg. from steel conforming to AISI 440C. This material is strongly magnetic. The balls are properly heat-treated, free of surface decarburization.

CORROSION RESISTING UNHARDENED STEEL BALLS-are mfg. from steel to AISI Type 316, unless otherwise specified. This material is only slightly magnetic.

BRASS BALLS-are mfg. from selected brass free from alloy segregation in the analysis of: Copper-60-70%, Zinc-30-40%.

ALUMINUM BALLS-are mfg. from material conforming to Aluminum Association Specification No. 2017 (SAE No. 26).

TUNGSTEN CARBIDE BALLS-are mfg. from high grade material in the range of Tungsten Carbide- 93.5-94.5%, Cobalt-5.5-6.5%.

BERYLLIUM COPPER BALLS-are mfg. from selected material free from alloy segregation: Beryllium-1.80-2.05%, Nickel & Cobalt-.20(minimum), Iron, Nickel & Cobalt-.60% (Maximum), Copper-Balance.

NYLON BALLS-are resistant to most common organic solvents, oils, greases and electrolytic corrosion. Nylon has a good heat resistance, high tensile strength, fatigue endurance, compression and shear strength, abrasion resistance, low coefficient of friction and very good electrical properties.

TEFLON BALLS-are unaffected by practically all organic solvents, strong caustics, cryogenic missile fuels, liquid oxygen and concentrated acids. Properties include: zero water absorption, highest heat resistance of all thermoplastics, good physicals from cryogenic temperatures to +500°F and good compressive strength.

POLYPROPYLENE BALLS-are resistant to organic solvents below about 80°C. It is very resistant to bases and weak acids, and is slowly attacked by oxidizing acids. These balls float in water and have a low water absorption.

MASTER TABLE OF BALL GRADES AND TOLERANCES

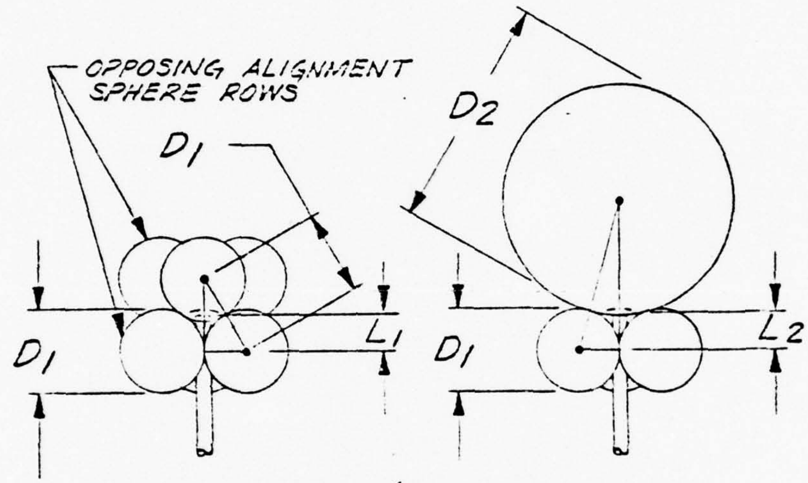
Grade	Diameter Tolerance per Ball	"V" Block Out-of-Round in 120° Angle	Diameter Tolerance per Unit Container	Basic Diameter Tolerance	Marking Increments	Maximum Surface Roughness Micro-inch
	inch	inch	inch	inch	inch	
3	.000003	.000003	.000005	±.00003	.000003	.5 (1)
5	.000005	.000005	.00001	±.00005	.000005	.7 (1)
10	.000010	.000010	.00002	±. 0001	.000010	1.0 (1)
15	.000015	.000015	.00003	±. 0001	.000015	1.2 (1)
25	.000025	.000025	.00005	±. 0001	.000025	1.5 (1)
50	.00005	.00005	.0001	±.0002	.00005	3.0
100	.0001	.0001	.0002	±.0005	.0001	5.0
200	.0002	.0002	.0004	±.0010	.0002	8.0
300	.0003	.0003	.0006	±.0015	.0003	NOT APPLICABLE
[illegible]	.0005	.0005	.001	±.002	.0005	
1000	.001	.001	.002	±.005	NOT APPLICABLE	
2000	.002	.002	.004	±.005		
3000	.003	.003	.006	±.005		

1) These grades may carry waviness requirements.

APPENDIX B

APPENDIX B

DERIVATION OF FIBER INSTALLATION FIXTURE TO ACHIEVE ZERO GAP



$$L_1 = \frac{\left[D_1^{\,2} - \frac{D_1}{3}^2\right]^{\frac{1}{2}}}{2} = \frac{\sqrt{\frac{2}{3}}\,D_1}{2} = \frac{D_1}{\sqrt{6}}$$

$$L_2 = \left[\left(\frac{D_1 + D_2}{2}\right)^2 - \frac{D_1}{3}^2\right]^{\frac{1}{2}} - \frac{D_2}{2}$$

LET $L_1 = L_2$

$$\left[\left(\frac{D_1 + D_2}{2}\right)^2 - \frac{D_1}{3}^2\right]^{\frac{1}{2}} - \frac{D_2}{2} = \frac{D_1}{\sqrt{6}}$$

$$D_2 = 4\,\frac{D_1}{\left(\frac{1}{2} - \frac{1}{\sqrt{6}}\right)} = 2.725\,D_1$$

$D_2 = 2.725\,D_1$ IF $D_1 = .03125''$, $D_2 = .085''$

$D_1 = .035''$, $D_2 = .095''$

APPENDIX C

TEST REPORT

REPORT NO. 56290

OUR JOB NO. NE56290

YOUR P. O. NO. 54583

CONTRACT N/A

4 Page Report

WYLE LABORATORIES / Norco, California . 737-0871 . 689-2104 . TWX 910-332-1204 . Cable WYLAB

Itt Cannon Electric
666 E. Dyer Road
Santa Ana, Ca 92702

DATE 24 May 1977

This is to certify that the enclosed test data sheets contain true and correct data obtained in the performance of the test program as set forth in your purchase order.

Test methods, results, and equipment used are recorded on these data sheets.

Where applicable, instrumentation used in obtaining this data has been calibrated using standards which are traceable to the National Bureau of Standards.

COMMENTS:

Seven (7) Samples of Fiber Optics Devices, part numbers and serial numbers as identified on the Receiving inspection data sheet. Page 2 of this report, were subjected to the Dust Test in accordance with MIL-STD-202E, Method 110A.

BEST AVAILABLE COPY

STATE OF CALIFORNIA }
COUNTY OF RIVERSIDE } ss.

Ray C. Myrick, being duly sworn, deposes and says: that the information contained in this report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

[signature]

SUBSCRIBED and sworn to before me this 24 day of May, 19 77

[signature]

Notary Public in and for the County of Riverside, State of California

My Commission expires 14 July 19 79

W-867B

DEPARTMENT ELECTRONICS

DEPT. MGR. [signature]
R. A. Wood

TEST ENGINEER [signature]

TEST WITNESS

DCAS-GAR VERIFICATION

QUALITY CONTROL [signature]
A. Reeseman

DATA SHEET

Customer LTT CANNON Job No. 56290

Date 5-20-77

Specimen FIBER OPTICS DEVICES

RECEIVING INSPECTION

BEST AVAILABLE COPY

No. of Specimens Received: 7 SAMPLES

Record identification information exactly as it appears on the tag or specimen

Manufacturer ITT CANNON

Part Numbers NONE

How does identification information appear: (name plate, tag, painted, imprinted, etc.)

TAG

Serial Numbers:* #1 5-18-STD JEWEL 3 SAMPLES INSULATED

#1, 5-17-3 SPHERE #1

#2, 5-18-3 SPHERE #2

#3 5-18: 3 SPHERE #3

Examination: Visual, for evidence of damage, poor workmanship, or other defects, and completeness of identification.

Inspection Results: There was no visible evidence of damage to the specimens unless noted below.

* If additional space is required for serial numbers, use an additional page, or reference first functional test data sheet (if applicable).

Inspected By [signature]

Sheet No. ___ of ___

Approved [signature] Date: 5-20-77

W-614
Q.C. Form Approved

WYLE LABORATORIES

DATA SHEET

Report No. 56290
Page No. 3

Test Title: DUST

Customer: ITT CANNON

Part No. NONE
S/N SEC REC. INSP.
Spec. MIL STD 202 E
Para. METHOD 110A

Job. No. 56290
Date Test Started 5-20-77
Date Test Completed 5-21-77
Amb. Temp. CONTROLLED
Photo NO
Test Med. SIL-CO-SIL 290
Specimen Temp. AMB.

Specimen TERMINA FIBER OPTIC DEVISES

BEST AVAILABLE COPY

Specification: The specimen* shall exhibit no evidence of damage or deterioration as a result of the Dust Test exposure.

Test Procedure: The specimen was installed in a dust chamber and the internal temperature of the chamber adjusted to 23 ±1.4C. The relative humidity was adjusted to less than 22 percent. The air velocity within the chamber was adjusted to 1750 ±250 feet per minute. The dust feeder was adjusted to control the dust concentration at 0.3 ±0.2 gms/ft^3. These conditions were maintained for a period of 6.0 hours, with the specimen non-operating.

At the conclusion of the 6.0 hour period, the dust feeder was stopped, the air velocity adjusted to 300 ±200 feet per minute, and the temperature raised to 63 ±1.4C. The relative humidity was adjusted to less than 10 percent. The specimen was maintained at these conditions for 16.0 hours.

At the conclusion of the 16.0 hour period, while maintaining chamber temperature at 63 ±1.4C, the air velocity was adjusted to 1750 ±250 fpm. The dust feeder was adjusted to control the dust concentration at 0.3 ±0.2 gms/ft^3. The specimen, non-operating, was maintained at these conditions for a period of 6.0 hours.

At the conclusion of this 6.0 hour period, the controls of the chamber were turned off and the specimen allowed to return to room ambient conditions.

Upon stabilization at room ambient conditions, if applicable, the specimen was operated by NOT APPLICABLE. Upon completion of specimen operation, a visual examination for evidence of damage or deterioration was performed.

Test Results: THE SPECIMENS WERE RETURNED TO THE CUSTOMER FOR EXAMINATION. HOWEVER, THE FIBERS OF SPECIMEN #1 (STD JEWEL) & #2 (G SPHERE) WERE BROKEN UPON REMOVAL FROM THE TEST FIXTURE AT THE COMPLETION OF THE TEST

*Or specimens

Specimen Meets Spec. Requirements YES ☐ NO ☐

Tested By [signature]
Witness ________ Date: ________
Sheet No. ________ of ________
Approved [signature] Date ________

Q.C. Form Approval [signature]

WYLE LABORATORIES

SPECIMEN [illegible] (FIBER [illegible]) JOB NO. 562 2
CUSTOMER ITT [illegible] DATE 5-26-77
PART NO. NA TEST BY C E [illegible]
S/N ONE LEVEL INSPT'D WITNESS
TEST Sand & Dust

EQUIPMENT	MANUFACTURER	MODEL NO.	RANGE	WYLE NO.	CALIBRATION LAST	CALIBRATION DUE	ACCY.
Sand & Dust Chamber Controller	WYLE	NA	-80 TO +180F	30487	NA	NA	NA
Temperature Recorder	HONEYWELL	[illegible]	-100 TO +300F	31457	2-7-77	6-5-77	± 0.5% FS
Air Sampler	Mine Safety Appliance	CT75355	150 [illegible]	30367	NA	NA	NA
Air Meter	Anemostat Products Div.	60	10 TO 8000 FPM	31357	11-8-76	11-8-77	± 5%
Analytical Balance	SEKO	301562	0 TO 2000 GMS	6307	System	Cal.	± 0.1 Mg
Weights	OHAUS	NA	100 MG TO 200 GMS	1028	5-25-76	5-25-77	Class P Metric

BEST AVAILABLE COPY

APPENDIX D

ITT CANNON ELECTRIC
666 EAST DYER ROAD
SANTA ANA, CALIF. 92702
PURCHASE ORDER NUMBER 55623
JUNE 21, 1977
REPORT NUMBER 142-445

Parker Hannifin Corporation
Air and Fuel Division
18321 Jamboree Blvd.
P. O. Box C-19510
Irvine, CA 92713 U.S.A.
Phone (714) 833-3000

A. TEST: VIBRATION, SINUSOIDAL

B. TEST ITEMS:
(2) THREE-SPHERE F O FERRULES
(1) SINGLE-CHANNEL F O CONNECTOR

C. REFERENCES:
MIL-STD-202E
METHOD 204C
TEST CONDITION A

Parker Hannifin Corporation
Air and Fuel Division
18321 Jamboree Blvd.
P. O. Box C-19510
Irvine, CA 92713 U.S.A.
Phone (714) 833-3000

D. TEST PROCEDURES AND TEST RESULTS:

This is to certify that each specimen was subjected to sinusoidal vibration in each of three mutually perpendicular axes over the frequency range of 10 to 500 to 10 HZ at an applied double amplitude of 0.06 inch up to a limiting value of 10.0 G-Peak.

The frequency range of 10 to 500 and return to 10 HZ was logarithmically scanned in 15 minutes. This cycle was performed 12 times in each of three mutually perpendicular axes.

No anomaly was observed.

Tests were performed at room ambient conditions consisting of a temperature of 22 ± 5°C and a relative humidity of less than 70 percent and Barometric pressure between 28 to 32 inches of mercury.

G. Hill,
Dynamics Test Specialist

R. J. Bruno,
Quality Engineering Supervisor

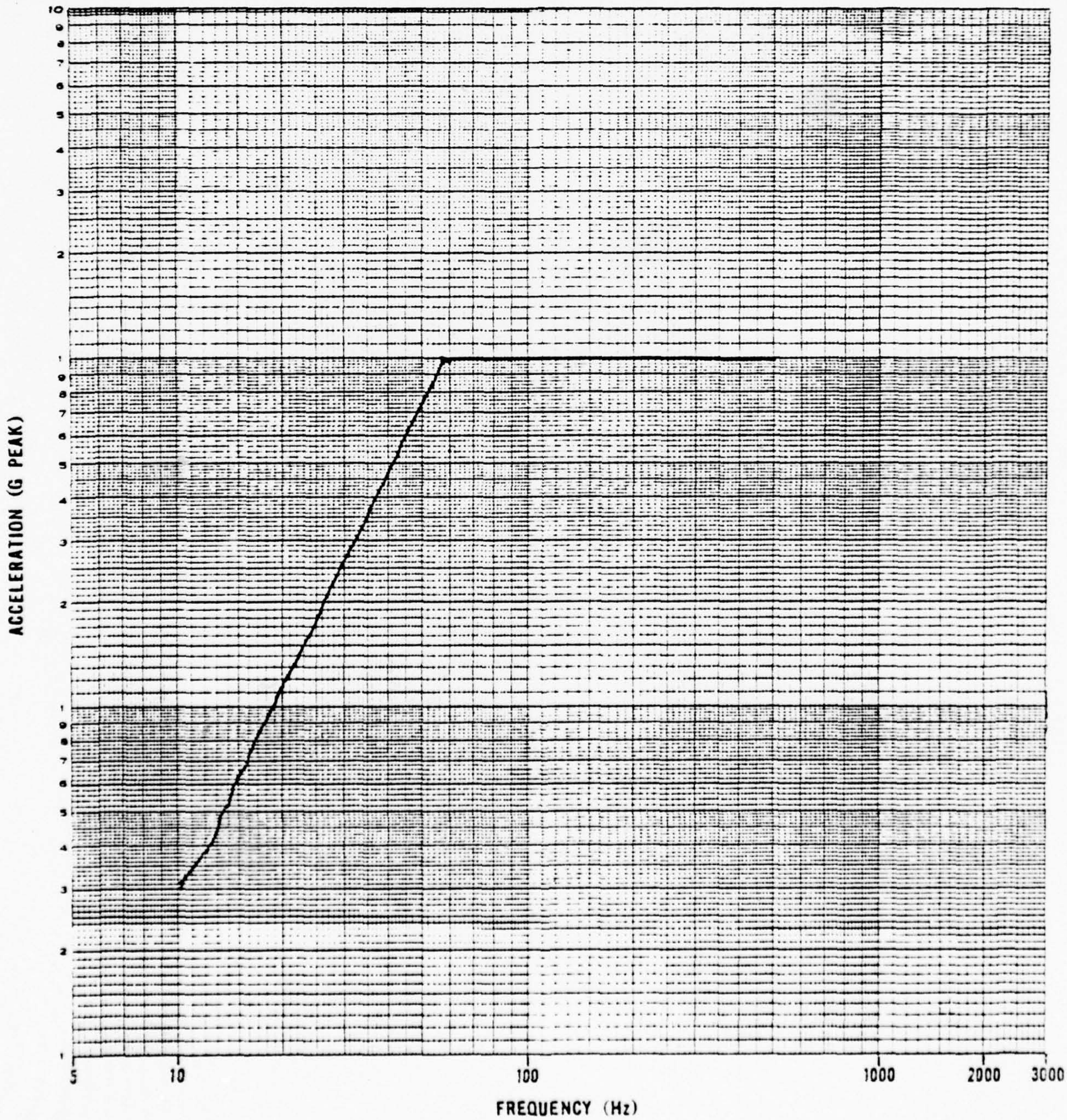
R. Urene,
Dynamics Laboratory Engineer

PARKER HANNIFIN

REPORT NO. 142-445	BY HILL	PAGE 3	
REV	DATE 6-21-77		

SINUSOIDAL VIBRATION ITT CANNON	PART NO. P.O.# 55623	DATA BY: G. HILL
SPECIMEN NAME: F.O. CONNECTOR	SERIAL NO. 1 LOT.	DATE: 6-20-77
	JOB NO. 142-445	

ACCELEROMETER NO. 1	RECORD NO. 3	SWEEP: UP ☒ DOWN ☐
CONTROL ☒ RESPONSE ☐	AXIS 3RD	FULL SCALE 100.0 G PEAK



PHLA P67 (9-69)

EQUIPMENT LIST ITT CANNON

SPECIMEN NAME: F.O. FERRULE & CONNECTOR

PART NO. P.O. # 55623

SERIAL NO. 1 LOT.

JOB NO. 142-445

DATA BY: G. HILL

DATE: 6-17-77

EQUIPMENT USED	MANUFACTURER	MODEL #	STK. #	RANGE	ACCURACY	CALIB. DUE
ACCELEROMETER	ENDEVCO	2224C	5043	0-1000G-PK	± 5%	9-24-77
V.T.V.M.	BRUEL & KJAER	2416	5891	.01-1000V	± 2%	7-10-77
OSCILLOSCOPE	HEW-PACKARD	122AR	5894	5MS TO 200MS/CM	± 5%	7-7-77
LOG. FREQ. CONV.	SPECTRAL DYN.	SD116	5682	5-20KHZ	± 5%	12-9-77
CHARGE AMP.	UNHOLTZ DICKIE	D-11	6959	0-1000G-PK	± 2%	12-8-77
SINE OSC. - SERVO	LING ELECT.	SCO-100	5681	0-300G-PK	± 4%	7-14-77
COUNTER-TIMER	ANADEX	CF-600R	5703	0-100KHZ	± 1PPM/WK	8-19-77
X-Y RECORDER	HEW. PACKARD	7005B	5941	1MV-10V	± .2%	12-9-77
VIBRATION EXCITER	M.B. MFG. CO	C-10	1936	1200 FORCE LBS.	5-3000 HZ	MAINT. ONLY
POWER AMP.	LING ELECT	5/6	1936	0-50AMPS	CLASS AB1	MAINT. ONLY

REPORT NO. 142-445 BY HILL PAGE 5

REV					
DATE	6-21-77				

PARKER HANNIFIN

SINUSOIDAL VIBRATION ITT CANNON

SPECIMEN NAME: F.O. FERRULES & CONNECTOR	PART NO. P.O. # 55623	DATA BY: G. HILL
	SERIAL NO. 1 LOT	DATE: 6-17-77
	JOB NO. 142-445	VIBRATION DATA SHT NO.

CONTROL ACCLRM NO. 1 SN DJ56 LOCATION ON FIXTURE AXIS *
OUTPUT ACCLRM NO. ____ SN ____ LOCATION ____ AXIS ____
OUTPUT ACCLRM NO. ____ SN ____ LOCATION ____ AXIS ____
OUTPUT ACCLRM NO. ____ SN ____ LOCATION ____ AXIS ____
OUTPUT ACCLRM NO. ____ SN ____ LOCATION ____ AXIS ____
OUTPUT ACCLRM NO. ____ SN ____ LOCATION ____ AXIS ____
OUTPUT ACCLRM NO. ____ SN ____ LOCATION ____ AXIS ____
OUTPUT ACCLRM NO. ____ SN ____ LOCATION ____ AXIS ____

FREQUENCY (Hz)	APPLIED FORCE DISPLACEMENT (IN. DA)	APPLIED FORCE PEAK (G)	OUTPUT FORCE (G PEAK)	ACCLRM NO.	SCAN	CYCLE	DWELL	TIME (MIN)	RECORD NO.	REMARKS
10-57	0.06					X		180.0	1	* EACH TEST ITEM
57-500		10.0								WAS EXPOSED TO
										VIBRATION IN EACH OF
									.	THREE ORTHOGANAL
10-57	0.06					X		180.0	2	AXES.
57-500		10.0								
10-57	0.06					X		180.0	3	
57-500		10.0								

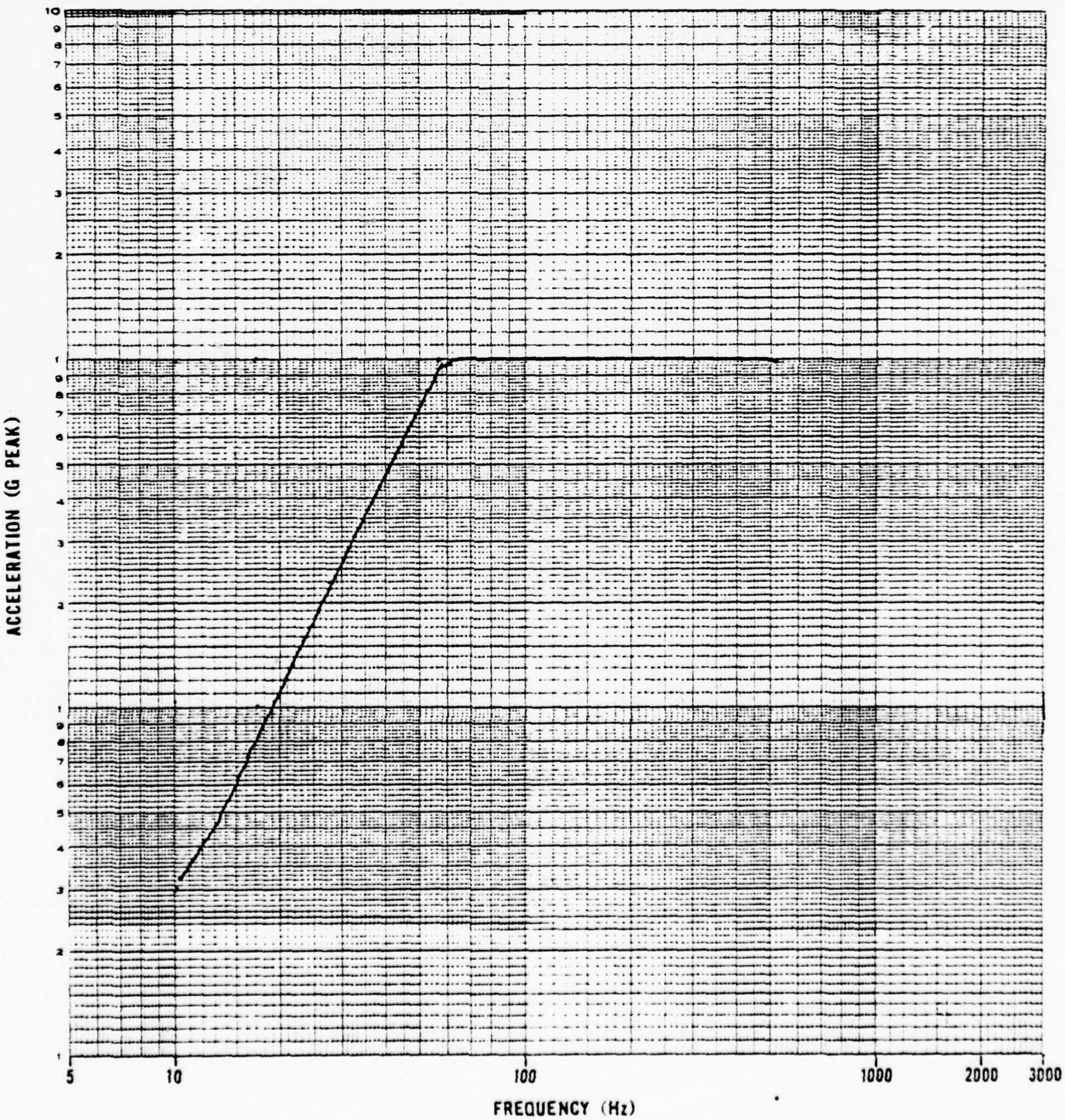
PHLA P56 (9-69)

PARKER HANNIFIN

REPORT NO. 142-445	BY HILL	PAGE 6
REV	DATE 6-21-77	

SINUSOIDAL VIBRATION ITT CANNON	PART NO. P.O. # 55623	DATA BY: G. HILL
SPECIMEN NAME: F.O. CONNECTOR	SERIAL NO. 1 LOT.	
	JOB NO. 142-445	DATE: 6-17-77

ACCELEROMETER NO. 1	RECORD NO. 1	SWEEP: UP ☒ DOWN ☐
CONTROL ☒ RESPONSE ☐	AXIS 1st	FULL SCALE 100.0 G PEAK



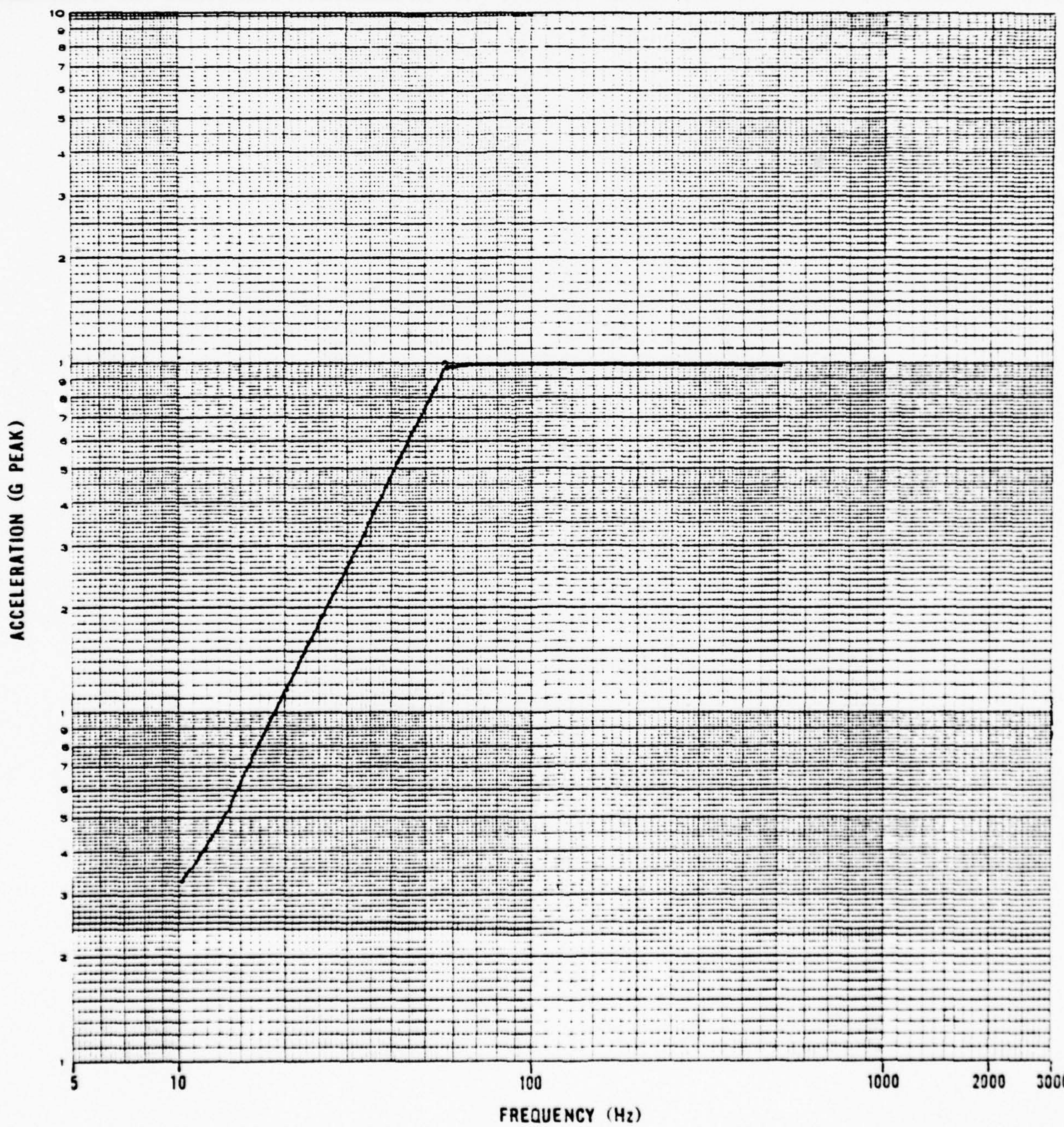
PHLA P67 (9-69)

REPORT NO. 142-445	BY HILL	PAGE 7
REV	DATE 6-21-77	

PARKER HANNIFIN

SINUSOIDAL VIBRATION ITT CANNON	PART NO. P.O. #55623	DATA BY: G. HILL
SPECIMEN NAME: F.O. CONNECTOR	SERIAL NO. 1 LOT	DATE: 6-20-77
	JOB NO. 142-445	

ACCELEROMETER NO. 1	RECORD NO. 2	SWEEP: UP [X] DOWN [ ]
CONTROL [X] RESPONSE [ ]	AXIS 2ND	FULL SCALE 100.0 G PEAK



PMLA P67 (9-69)

APPENDIX E

THERMAL SHOCK

Samples were subjected to 5 continuous cycles of thermal shock. Each cycle consisted of 0.5 hr (1.8 ks) at -55 °C and 0.5 hr (1.8 ks) at 85 °C. Maximum dwell time between temperature extremes was 120 seconds.

Requirement:

There shall be no damage detrimental to the operation of the sample.

Report Number	Data Sheet No.
	1
Date Started	**Date Completed**
22 Jun 77	22 June 77

Test Group	Sample Numbers
—	Single FO Connector

Tested By: R. S. [signature]

Temp °C	Humidity %	Pressure	Data Unit

Test Equipment

Type	Number	Cal Date	Due Date
Thermal Shock Test Chamber	642	7 June 77	7 June 78
Potentiometer	818	7 June 77	25 Sep 77

Data Summary

Description	< x <	$\bar{x}$	P/F

The sample connector was mounted in the test cell of the Thermal Shock Test Chamber which had been programmed to perform the MIL-STD-202, Method 107, Test Condition A. The ends of the fiber optic cable were brought outside the test chamber and connected to the monitoring equipment shown on Data Sheet 16. An initial reference level was taken before actuating the Thermal Cycling equipment. Power level measurements were taken periodically throughout the thermal cycle and are recorded on sheets 1-15

II, CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		2

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
Monitor Optical Power through the mated connector during 5 cycles of Temperature Cycling per MIL-STD-202, Method 107, Test Condition A.	—	Single FO Connector

Tested By: R. A. Sherrard

Temp °C	Humidity %	Pressure	Data Unit
			Noted

Test Equipment

Type	Number	Cal Date	Due Date
Power Supply	952	30 MAR 77	1 JUL 77
Voltmeter	521	25 MAY 77	9 Sep 77
1 Ω Resistor	110	26 APR 77	28 Apr 78
Ammeter	703	12 May 77	26 Aug 77
Voltmeter	870	13 May 77	26 Aug 77

Data Summary

Description	≤ x ≤		x̄	P/F
Output	0.72	36		Eval

	Time	Drive (A) If	Drive (V) Vf	Output (nA)			
	1449	.2001	1.909	27.8 nA	← Initial	Reference	Level
0	1452	.2001		27.8 nA	Start	-55°C	1st Cycle
2	1454	.2001		28.1 nA			
8	1500	.2006		28.2 nA			
11	1503	.2001	1.911	28.1 nA			
18	1510	.2001	1.910	27.8 nA			
23	1515	.2001		27.7 nA			
28	1520	.2002		28.0 nA			
30	1522	.2001		28.2 nA	End	-55°C	1st Cycle
	1523	.2002		28.5 nA	Start	85°C	1st Cycle
	1524	.2000		28.5 nA			
	1525	.2002		18 nA			
	1526	.2002	1.910	17 nA			
	1527	.2001		15.2 nA			
	1529	.2000		16.5 nA			
	1530	.1999		17.5 nA			
	1531	.1999		19.5 nA			
	1532	.1999		19.5 nA			
	1535	.2001		18.5 nA			
	1537	.2001		18.2 nA			
	1540	.2001	1.910	18.0 nA			
	1545	.2001		17.5 nA			
	1550	.2000		17.2 nA			
	1553	.2000		17.5 nA	End	85°C	1st Cycl

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		3
Reference Specifications RPI 534 & ECOM Technical Guidelines	**Date Started** 22 Jun 77	**Date Completed** 22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single F O Connector
	Tested By R. A. [signature]	

Temp °C	Humidity %	Pressure	Data Unit
			Noted

Test Equipment				Data Summary			
Type	Number	Cal Date	Due Date	Description	≤ x ≤	x̄	P/F

Time	Drive (A) If	Drive (V) Vf	Output (nA)			
1555	.1999		20	Start	-55°C	2nd Cycle
1556	.2000	1.909	32			
1557	.2000		30			
1557.3	.1999		22			
1557.5	.1999		15			
1557.8	.1999		14			
1558	.2001		10			
1558.5	.2001		6.2			
1559	.2001		4.8			
1559.3	.2001		4.0			
1559.5	.2001		3.2			
1559.8	.2000		2.8			
1600	.2001		2.5			
1600.3	.2001		2.2			
1600.5	.2001		2.0			
1601.5	.2000		2.0			
1601.5	.2002		1.75			
1602	.2002		1.65			
1605	.2005		1.4			
1610	.2000		1.3			
1612	.2003	1.909	1.25			
1615	.2000	1.910	1.25			
1617	.1999	1.910	1.22			
1620	.2000	1.910	1.20			
1623	.2002	1.910	1.15			

ITT CANNON ELECTRIC

Test		Report Number	Data Sheet No.
Power Level during TEMCYC			4
Reference Specifications: RPI 534 & Technical Guidelines		Date Started: 22 Jun 77	Date Completed: 22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector
	Tested By: R. A. [illegible]	

Temp °C	Humidity %	Pressure	Data Unit
—	—	—	Noted

Test Equipment: Type	Number	Cal Date	Due Date	Data Summary: Description	≤ x ≤		x̄	P/F

Time	Drive (A) (I_f)	Drive (V) V_f	Output (nA)			
1525	.2000	1.909	1.	End	-55°C	2nd Cycle
1525.5	.2000	1.910	0.75			
1526	.2001	1.910	0.72	Room Temp		
1527	.2003	1.910	1.2			
1527.5	.2003	1.910	2.1			
1528	.2004	1.910	25	Start	85°C	2nd Cycle
1528.3			23.2			
1628.5			24.5			
1628.8			29			
1629.0	.2005		30			
1629.5	.2005		31			
1630	.2005		17			
1630.5	.1998	1.909	16.7			
1632	.1999	1.909	15			
1633	.1999	1.909	15			
1634	.2003	1.910	15.2			
1639	.1999	1.909	15.2			
1645	.2001	1.909	15.2			
1653	.2003	1.909	15.5			
1655	.1998	1.908	15.5			
1657	.1999	1.907	16.5	End	85°C	2nd Cycle
1659	.1998	1.907	16			
1700	.2000	1.908	16.5	Room	Temp	
1700.8			.32	Start	-55°C	3rd Cycle
1701	.1999	1.908	32			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		5

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector
	Tested By	R. A. Shumel

Temp °C	Humidity %	Pressure	Data Unit
—	—	—	Noted

Test Equipment				Data Summary			
Type	Number	Cal Date	Due Date	Description	≤ x ≤	x̄	P/F

Time	Drive (A) If	Drive (V) Vf	Output (nA)			
1702.5			24		-55°C	3rd Cycle
1702.8			18			
1703			16			
1703.1			15			
1703.3			12			
1703.8			10			
1704			9.2			
1704.5	.1999	1.908	8			
1705	.1999	1.908	7.2			
1705.5	.2000		6.6			
1706	.2000		6.4			
1706.5	.2000	1.908	6.2			
1707	.2000	1.908	6.0			
1707.5	.2001	1.908	6.0			
1708	.2001	1.908	5.9			
1710	.2004	1.909	5.8			
1715	.2000	1.908	5.7			
1722	.2006	1.910	5.6			
1725	.2006	1.910	5.6			
1730	.2006	1.910	5.6			
1731				End	-55	3rd
1731.3	.2004	1.909	5.2	Room	Temp	
1731.5	.2003		4.8			
1731.8			4.8			
1732	.2003	1.909	5.0			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level During TEMCYC		6

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector

Tested By: R. A. [signature]

Temp °C	Humidity %	Pressure	Data Unit
—	—	—	Noted.

Test Equipment				Data Summary			
Type	Number	Cal Date	Due Date	Description	≤ x ≤	x̄	P/F

Time	Drive (A) If	Drive (V) Vf	Output (nA)			
1732.3	.2003	1.909	5.4	Room	Temp	
1732.5	.2003	1.909	5.8			
1732.8	.2003	1.909	6.4			
1733.0	.2003	1.910	6.8	End	Room Temp	
1733.5			20	Start	85°C	3rd Cycle
1733.6	.2003	1.909	25			
1733.8	.2003	1.909	24.5			
1734.0			26			
1734.1			29			
1734.3	.2004	1.910	31			
1734.5	.2004	1.910	32			
1734.6	.2004	1.910	32			
1734.8	.2004	1.910	32			
1735.0	.2004	1.910	30			
1735.2	.2004		22			
1735.4	.2004		14			
1735.5	.2004		18			
1735.8	.2004	1.909	16			
1736.0	.2004	1.910	15.2			
1736.5	.2005	1.910	15.2			
1737	.2007	1.911	15.0			
1738	.2004	1.909	14.8			
1739	.2004	1.909	14.6			
1742	.2003	1.909	14.4			
1745	.2000	1.908	14.3			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		7

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector

Tested By: R. A. [signature]

Temp °C	Humidity %	Pressure	Data Unit

Test Equipment				Data Summary				
Type	Number	Cal Date	Due Date	Description	≤ x ≤		x̄	P/F

Time	Drive (A) If	Drive (V) Vf	Output (nA)			
1752	.2002	1.909	14.8			
1755	.2002	1.909	14.8			
1800	.2004	1.910	15.0			
1803	.2002	1.909	15.0	End	85°C	3rd Cycle
1804	.2000	1.908	15.2	Room	Temp	
1805	.2001	1.909	15.5			
1805.2	.2002	1.909	15.5			
1805.4	.2002	1.909	16			
1805.6	.2001	1.909	15	End	Room	Temp
1805.9			14	Start	-55°C 4th	Cycle
1806.1			19			
1806.2			34			
1806.4			34			
1806.5			33			
1806.6			33			
1806.7	.2001	1.909	33			
1806.8	.2001	1.909	33			
1806.8	.2001	1.909	34			
1807.2	.2001	1.909	34			
1807.4	.2001	1.909	34			
1807.6	.2001	1.909	34			
1807.8			32			
1807.9			28			
1808.0			26			
1808.2	.2006	1.909	24			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during Temcyc		8
Reference Specifications	**Date Started**	**Date Completed**
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector

Tested By: R. A. [signature]

Temp °C	Humidity %	Pressure	Data Unit
—	—	—	Noted

Test Equipment

Type	Number	Cal Date	Due Date

Data Summary

Description	≤ x ≤		x̄	P/F

Time	Drive (A) Ip	Drive (V) Vp	Output (nA)			
1808.4	.2000	1.909	21		-55°C	4th Cycle
1808.6	.1999	1.909	19			
1808.8	.1999	1.908	17			
1809.0	.1998	1.908	15.5			
1809.2	.1999	1.909	14			
1809.4	.1999	1.909	13.5			
1809.6	.1999	1.909	13			
1809.8	.1999	1.909	12			
1810.0	.1999	1.909	11			
1810.2	.2000	1.909	10.5			
1810.4	.2000	1.909	10			
1810.6	.1999	1.909	9.8			
1810.8	.2000	1.909	9.3			
1811.0	.2000	1.909	9.1			
1811.3	.2001	1.909	9.0			
1811.5	.2002	1.909	8.8			
1812.0	.2002	1.909	8.5			
1812.5	.2002	1.909	8.2			
1813.0	.2002	1.909	8.2			
1813.5	.2003	1.910	8.0			
1814.0	.2003	1.910	8.0			
1814.0	.2003	1.910	7.9			
1815	.2004	1.910	7.8			
1815.5	.2004	1.910	7.8			
1816.0	.2004	1.910	7.6			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		9

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector

Tested By: R. S. [signature]

Temp	Humidity	Pressure	Data Unit
— °C	— %	-	Noted

Test Equipment				Data Summary				
Type	Number	Cal Date	Due Date	Description	≤ x ≤		x̄	P/F

Time	Drive (A) If	Drive (V) Vf	Output (nA)			
1817	.2005	1.910	7.5		-55°C	4th Cycle
1818	.2006	1.911	7.5			
1819	.2007	1.911	7.5			
1820	.2005	1.910	7.5			
1821	.1999	1.908	7.2			
1822	.1999	1.908	7.2			
1825	.1998	1.908	7.2			
1830	.1999	1.909	7.1			
1833	.1999	1.908	7.0			
1835.6			7.0	End	-55°C	4th Cycle
1836			7.0	Room	Temp	
1836.3	.1999	1.909	6.8			
1836.4	.1999	1.909	6.5			
1836.5	.1999	1.909	6.2			
1836.8	.1999	1.909	6.2			
1837.1	.1999	1.909	6.5			
1837.3	.1999	1.909	7.0			
1837.5	.1999	1.908	7.2			
1837.6			7.5			
1837.7	.1999	1.909	8.0			
1837.8	.1999	1.909	8.2	End	Room Temp	
1838.2	.1999	1.909	9.0	Start	85°C	4th Cycle
1838.4			12			
1838.5			19			
1838.6			24			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		10

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 June 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector

Tested By: R. A. [signature]

Temp	Humidity	Pressure	Data Unit
— °C	—	—	Noted

Test Equipment

Type	Number	Cal Date	Due Date

Data Summary

Description	≤ x ≤	x̄	P/F

Time	Drive If (A)	Drive Vf (V)	Output (nA)			
1838.7	.1998	1.909	26		85°C	4th Cycle
1838.8	.1998	1.909	26			
1839.0	.1998	1.909	27			
1839.2	.1999	1.909	30			
1839.4	.1999	1.909	32			
1839.5	.1999	1.909	33			
1839.6	.1998	1.909	33			
1839.8	.1996	1.908	33			
1840.0	.1996	1.908	34			
1840.3			24			
1840.4	.1995	1.907	20			
1840.5	.1996	1.908	19			
1840.7	.1996	1.908	17.5			
1840.9	.1996	1.908	16.5			
1841.0	.1995	1.907	16.3			
1841.5	.2000	1.909	16.0			
1842.0	.1999	1.909	15.8			
1843	.1998	1.908	15.2			
1844	.1998	1.908	15.0			
1845	.1998	1.908	15			
1850	.2003	1.910	14.8			
1855	.2003	1.910	14.9			
1900	.2005	1.910	15.1			
1905	.2000	1.909	15.2			
1908.5	.2000	1.909	15.2	End	85°C	4th Cycle

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during Temcyc		11
Reference Specifications: RPI 534 & ECOM Technical Guidelines	Date Started: 22 Jun 77	Date Completed: 22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector
	Tested By: R. A. [signature]	
	Temp °C: — / Humidity %: — / Pressure: —	Data Unit: Noted.

Test Equipment: Type	Number	Cal Date	Due Date	Data Summary: Description	≤ x ≤	x̄	P/F

Time	Drive If (A)	Drive Vf (V)	Output (nA)			
1908.8	.2000	1.909	15.2	Room	(start)	
1909.4	.2000	1.909	15.5			
1909.6	.2000	1.909	15.5			
1909.8	.2000	1.909	15.8			
1910.0	.1999	1.909	16.0			
1910.2	.1999	1.909	16.0			
1910.4	.1999	1.909	16.2			
1910.6	.1998	1.909	16	End	Room Temp	
1910.8			15.5			
1911.0			17.5	Start	-55 °C	5th Cycle
1911.3			34			
1911.4	.1998	1.908	34			
1911.6	.1998	1.908	34			
1911.8	.1998	1.908	34			
1912.0	.1998	1.908	34			
1912.2	.1998	1.908	34			
1912.4	.1998	1.908	35			
1912.5	.1998	1.908	35			
1912.7	.1997	1.908	33			
1912.9	.1997	1.908	30			
1913.0	.1997	1.908	28			
1913.3	.1999	1.908	25			
1913.5	.1996	1.908	23			
1913.7	.1996	1.908	20			
1913.8	.1996	1.908	17			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		12

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector

Tested By: R. J. Shenel

Temp °C	Humidity %	Pressure	Data Unit
—	–	–	Noted

Test Equipment				Data Summary				
Type	Number	Cal Date	Due Date	Description	≤ x ≤		x̄	P/F

Time	Drive If (A)	Drive Vf (V	Output (nA)			
1914	.1995	1.907	15.5		-55°C	5th Cycle
1914.3	.1995	1.907	13.5			
1914.5	.2003	1.910	13			
1914.8	.2002	1.910	12			
1915.0	.2002	1.909	11			
1915.3	.2000	1.909	10			
1915.5	.2000	1.909	9.5			
1916.0	.1999	1.909	8.9			
1916.5	.1999	1.909	8.0			
1917.0	.1999	1.909	7.5			
1917.5	.2001	1.909	7.5			
1918.0	.2001	1.909	7.2			
1919.0	.2003	1.910	7.0			
1920.	.2005	1.910	6.9			
1921	.2004	1.910	6.9			
1922	.2004	1.910	6.5			
1923	.2004	1.910	6.5			
1924	.2006	1.911	6.5			
1925	.2005	1.911	6.3			
1930	.2005	1.910	6.1			
1937	.2002	1.910	6.0			
1940	.2003	1.910	6.0			
1941.2				End	-55°C	5th Cycle
1941.5			5.5	Room	(Start)	
1941.7			5.5			

Test		Report Number	Data Sheet No.
Power Level during TEMCYC			13
Reference Specifications		Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines		22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector

Tested By: R. J. [signature]

Temp °C	Humidity %	Pressure	Data Unit
—	–	–	Noted

Test Equipment				Data Summary				
Type	Number	Cal Date	Due Date	Description	≤ x ≤		x̄	P/F

Time	Drive I_f (A)	Drive V_f (V)	Output (nA)			
1941.9	.2002	1.910	5.0			
1942.0	.2003	1.910	5.0			
1942.2	.2002	1.910	5.0			
1942.5	.2003	1.910	5.3			
1942.7	.2003	1.910	5.5			
1942.8	.2003	1.910	6.0			
1943.0	.2003	1.910	6.0			
1943.2	.2004	1.910	6.5			
1943.4	.2004	1.910	7.0			
1943.6	.2004	1.910	7.2	End	Room Temp	
1943.8	.		9.	Start	85°C	5th Cycle
1944.0	.2004	1.910	13			
1944.2			23			
1944.3			27			
1944.3	.2004	1.910	27			
1944.4			28			
1944.5	.2004	1.910	30			
1944.6	.2004	1.910	34			
1944.7	.2004	1.910	34			
1944.8	.2004	1.910	34			
1945.0	.2003	1.910	34			
1945.2	.2003	1.910	34			
1945.4	.2003	1.910	35			
1945.6	.2003	1.910	35			
1945.8	.2003	1.910	33			

ITT CANNON ELECTRIC

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		14

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single F.O. Connector

Tested By: R. A. [signature]

Temp °C	Humidity %	Pressure	Data Unit
			Noted

Test Equipment

Type	Number	Cal Date	Due Date

Data Summary

Description	≤ x ≤		$\bar{x}$	P/F

Time	Drive If (A)	Drive Vf (V)	Output nA			
1946.0	.2001	1.910	20		85°C	5th Cycle
1946.2	.2002	1.910	19			
1946.3	.2001	1.910	18			
1946.4	.2001	1.910	17.5			
1946.5	.2001	1.910	17			
1946.6	.2001	1.910	17			
1946.7	.2002	1.910	17			
1946.8	.2002	1.910	17			
1946.9	.2003	1.910	16.8			
1947.0	.2003	1.910	16.7			
1947.2	.2003	1.910	16.5			
1947.5	.2003	1.910	16.2			
1948.0	.2002	1.910	16			
1948.5	.2003	1.910	15.8			
1949.0	.2004	1.911	15.5			
1949.5	.2005	1.911	15.5			
1950	.2004	1.911	15.2			
1951	.2002	1.910	15.0			
1952	.2000	1.909	15.0			
1953	.2000	1.909	15.0			
1954	.2001	1.909	14.8			
1955	.2001	1.909	14.8			
2000	.2006	1.910	15.5			
2007	.2005	1.910	15.5			
2010	2006	1.910	15.5			

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		15
Reference Specifications	**Date Started**	**Date Completed**
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
	—	Single FO Connector
	Tested By R. A. Sherwood	

Temp °C	Humidity %	Pressure	Data Unit
—	—	—	Noted

Test Equipment				Data Summary				
Type	Number	Cal Date	Due Date	Description	< x <		$\bar{x}$	P/F

Time	Drive If (A)	Drive Vf (V)	Output (nA)			
1814.0	.2005	1.910	15.5	End	85°C	5th Cycle
1814.5	.2005	1.910	16	Room	Temp	
1815.0	.2006	1.911	16			
1815.5	.2006	1.911	16.2			
1816.0	.2006	1.911	17			
1816.5	—	—	—			
1817.5	.2006	1.911	20			
1817.8	.2006	1.911	23			
1818.0	.2006	1.911	24			
1818.3	.2006	1.911	29			
.5	.2006	1.911	31			
.6	.2007	1.911	32			
.7	.2007	1.911	33			
.8	.2007	1.911	34			
1819.0	.2007	1.911	34			
1819.5	.2007	1.911	36			
1819.8	.2007	1.911	36			
1920	.2006	1.911	36			
1920.5	.2007	1.911	36			
1921.0	.2003	1.910	36			
1922	.2003	1.910	36			
1923	.2003	1.910	36			

Test	Report Number	Data Sheet No.
Power Level during TEMCYC		16

Reference Specifications	Date Started	Date Completed
RPI 534 & ECOM Technical Guidelines	22 Jun 77	22 Jun 77

Test Method & Requirement	Test Group	Sample Numbers
Monitor circuit for Power Level Measurements	—	Single FO Connector

Tested By: R.A. Sherman

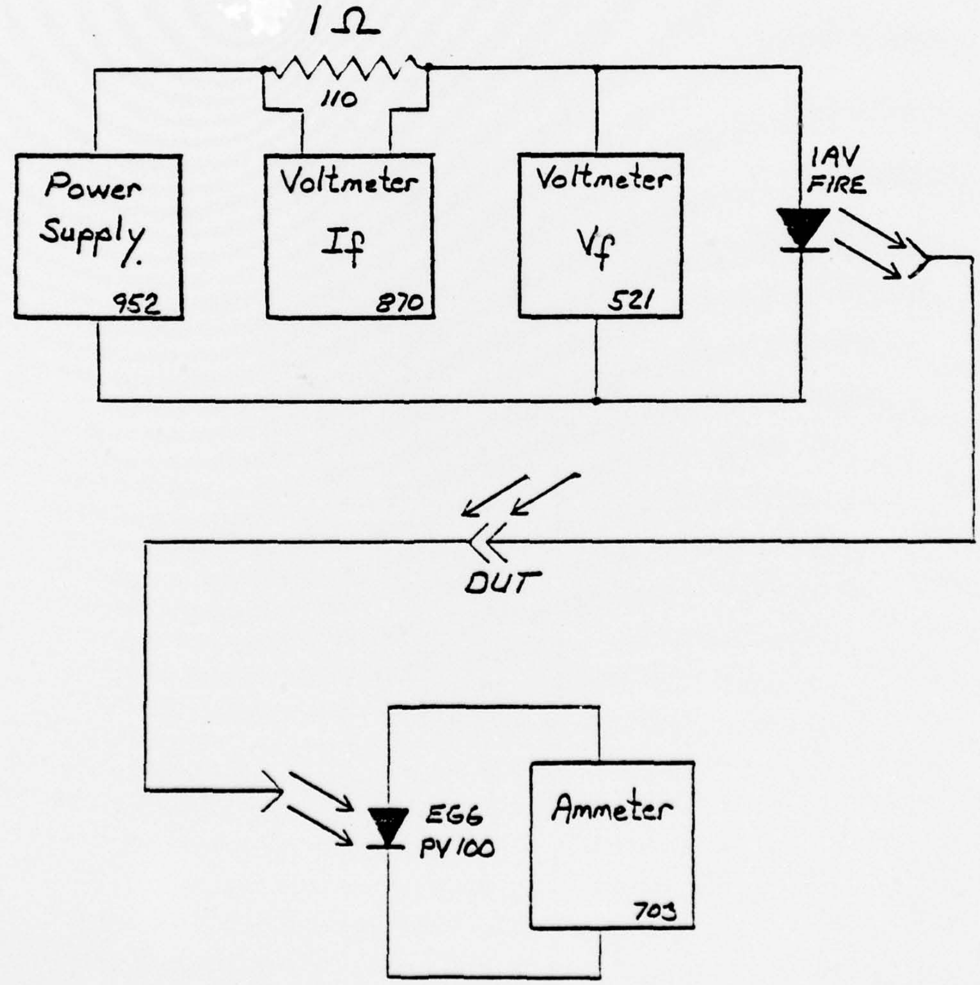
Temp °C	Humidity %	Pressure	Data Unit

Test Equipment

Type	Number	Cal Date	Due Date
Power Supply	952	30 Mar 77	1 Jul 77
Voltmeter	521	25 May 77	9 Sep 77
Resistor Standard	110	26 Apr 77	28 Apr 78
Ammeter	703	12 May 77	26 Aug 77
Voltmeter	870	13 May 77	26 Aug 77

Data Summary

Description	≤ x ≤		x̄	P/F



CANNON ELECTRIC